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UNITED STATES AIR FORCE PARACHUTE HANDBOOK

PARACHUTE BRANCH
EQUIPMENT LABORATORY
DIRECTORATE OF DEVELOPMENT

DECEMBER 1956

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UNITED STATES AIR FORCE PARACHUTE HANDBOOK

PARACHUTE BRANCH
EQUIPMENT LABORATORY
DIRECTORATE OF DEVELOPMENT

DECEMBER 1956

EQUIPMENT LABORATORY
PROJECT No. 6078

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
700 - March 1957

FOREWORD

The United States Air Force Parachute Handbook was prepared by personnel of . Parachute Branch, Equipment Laboratory, WADC, to serve as a guide for planning, and for general design purposes, for parachutes and parachute systems at the present stage of development.

It will be noted that parachute designs in general are growing more and more involved, and that specialization of types is occuring, and will probably continue to occur, at an accelerated rate. Each type has specific advantages and faults, which must be balanced against purpose and application.

One point must be stressed: successful parachute systems are expensive, and they require thoughtful, painstaking engineering to secure reliable operation. Parachute systems cannot be added, as an afterthought, late in missile or aircraft developments without causing a great amount of redesign and prejudicing the final reliability of the system.

This Handbook represents the first major revision of the USAF Parachute Handbook, especially with respect to design and construction of parachutes, test equipment, and test methods associated with their development. It is planned to revise the Handbook contents periodically, as enough new and reliable data become available to warrant reprinting.

Recommendations with respect to corrections, deletions, addition, or any other changes to improve the format and/or contents of this Handbook should be forwarded to Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, Attn: WCLEH-4.

ABSTRACT

The United States Air Force Parachute Handbook is a collection of information, test results, and other technical data pertaining to the application, design, construction, and testing, of parachutes, parachute systems, and accessories. The contents of this Handbook represent the state-of-the-art of parachute development, design, fabrication, and testing, and will be amended as the state-of-the-art advances.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Warren P. Shepardson

WARREN P. SHEPARDSON
Chief, Parachute Branch
Equipment Laboratory
Directorate of Development
Wright Air Development Center

ACKNOWLEDGEMENTS

The compilation of this Handbook was accomplished as a joint effort by all members of the Parachute Branch, Equipment Laboratory, Directorate of Development, Wright Air Development Center, with Mr. Rudi J. Berndt acting as Project Engineer and coordinator. The suggestions and contributions of each one of the members of the Parachute Branch were greatly appreciated.

McGraw-Hill Book Company, Inc., New York, New York, under Contract No. AF33-(616)-2694, was responsible for the arrangement of the material in book form, editing of the final text, and the artwork.

The cooperation of the personnel of the 6511th Test Group (Parachute), NAAS, El Centro, California, in supplying supporting data was greatly appreciated.

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GLOSSARY OF PARACHUTE TERMS AND STANDARD SYMBOLS

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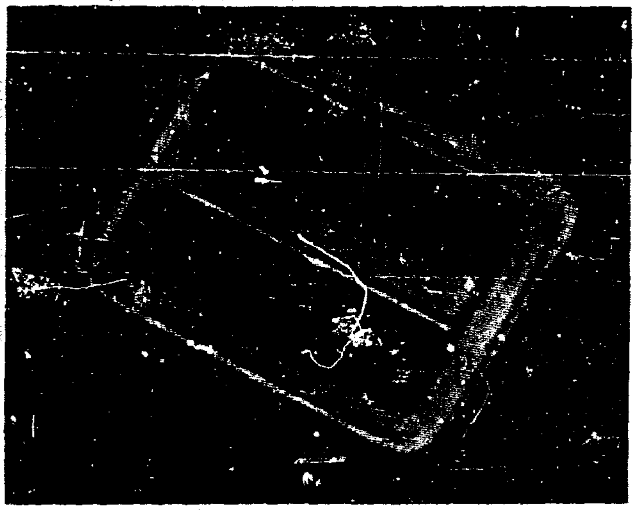
CHAPTER I

SECTION 1

GLOSSARY OF PARACHUTE TERMS

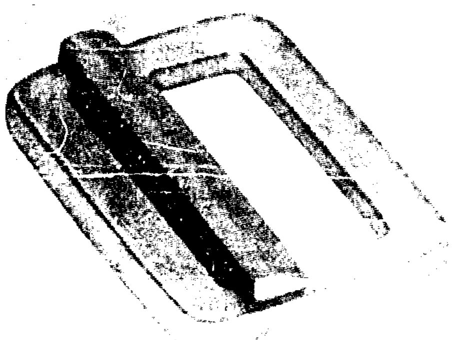
The following definitions are provided to aid in the correct interpretation of the data contained in this handbook and in other reports and articles on parachutes and their uses published by the United States Air Force.

accordion folding. See folding, accordion.



Adapter, Harness Strap

adapter, harness strap - a rectangular metal fitting with a crossbar. It is incorporated in a parachute harness to permit proper adjustment of webbing.



Adapter, Harness, Quick Fit

adapter, harness, quick fit - an adapter with the fixed crossbar replaced by a floating friction grip. The adapter is incorporated in a harness web to permit quick adjustment.

air bags - flexible, gas-filled bags that are inflated during load descent and valved to release their pressure upon ground contact to absorb impact forces.

apex - the center and topmost point of an inflated parachute canopy.

awl - a small, sharp pointed tool used to make holes in the fabric for hand sewing.

backstitch - used to anchor a row of stitching by turning material and sewing back over original stitching a short distance.

backstrap - a part of the harness that extends across the small of the wearer's back. It may or may not be adjustable.

bag, deployment - a fabric container, containing a parachute canopy, often enclosed in a parachute pack. There may or may not be provision for stowing suspension lines on the bag. Usually, either a static line or pilot chute lifts the deployment bag away from the parachute pack. With this system the suspension lines are extended before the canopy emerges from the deployment bag.

band, lateral, lower - a webbing band inserted in the skirt hem of the drag producing surface to reinforce the skirt.

band, lateral, upper - a webbing band inserted in the vent hem of the drag producing surface to reinforce the vent.

band, pocket - a piece of tape or line attached at the outside of the skirt, across radial seams, in a manner that causes the gores to be pulled outward at inflation, thus improving the opening characteristics of the canopy.

band, reinforcement - reinforcing tape, webbing, or ribbon, inserted in varied positions to reinforce weak points of construction or design in a drag producing surface.

band, retainer - a rubber band used to hold folded suspension lines or static lines to pack.

bar, packing - a long, flat, bar of metal, plastic, or wood, used to fold the canopy of a parachute during the packing process, and to aid in closing the pack.

bartack - a concentrated series of zigzag-like stitches used to reinforce points of stress.

basting - temporary stitching, usually with long, loose stitches.

binding - a piece of tape or fabric folded over and stitched to a raw edge of the fabric to prevent raveling or fraying.

blanketing - a result, caused by the relative air flow over a load or body, which opposes the intended action of a pilot chute or parachute canopy by reversal of flow and turbulence.

board, tension - a device that is usually hooked to the parachute connector links to place tension on the canopy during inspection and packing.

bobbin - a small, metal spool used to hold thread, as in a sewing machine.

bodkin - a large-eyed needle, flat or round, and usually blunt, used to draw tape, ribbon, elastic, or cord through a loop or hem.

bolt - a compact package or roll of fabric of any standard width, used in the United States as a measuring term for a length of 40 yards of material.

bottom, false - a piece of pack fabric stitched to the inside of a pack for the purpose of retaining the pack frame; it also serves as a base for stitching of the suspension line retaining loops.

breakcord - a thread or tape tied between parachute components that is intended to break under desired load during deployment.

breathing, canopy - the pulsating or pumping action of an inflated parachute canopy during descent.

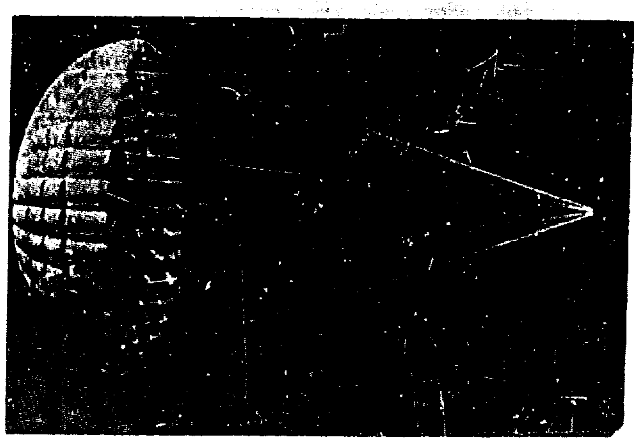
bridle - the arrangement of cords attaching the pilot chute to the apex of one or more parachute canopies, or to the deployment bag or bags containing those canopies.

bungees. See elastics, pack opening.

burns, friction - the result of rapid rubbing together of two textile surfaces, generating frictional heat, which reduces the tensile strength of the textile and causes deterioration of individual threads. It occurs primarily during parachute deployment and initial inflation.

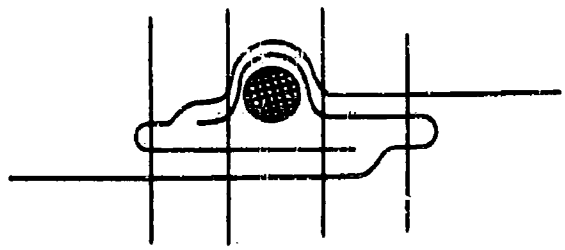
cabinet, drying - a facility used for the accelerated drying of parachutes.

cable, ripcord - a flexible cable joining the locking pins and the ripcord grip. The ripcord cable usually is of carbon steel or corrosion-resistant flexible steel, normally 3/32 inch in diameter. It consists of seven strands with seven wires per strand.



Canopy

canopy - the portion of a parachute consisting of the drag producing surface (cloth area) and the suspension lines extended to a mutual confluence point.



Channel, Parachute Canopy

channel, parachute canopy - the space or opening through which the suspension lines are passed. It is formed by the overlapping of the fabric in the main seams, or by the addition of cover tape to the drag producing surface.

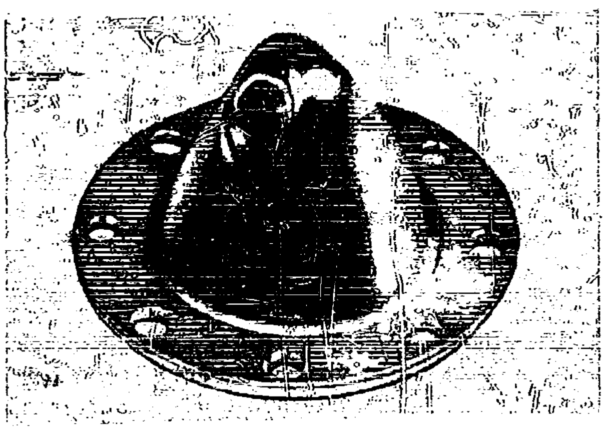
cheststrap - one of the harness straps sewed across the chest with a snap and a V-ring to prevent the wearer from falling out of the harness.

chute - a term used interchangeably with the word "parachute."

clevis - a U-shaped metal fitting with a hole in each end to receive a pin or bolt. It is used on cargo parachutes and heavy drop kits.

clip, safety - a U-shaped metal fitting used to prevent the accidental opening of the parachute harness release.

cluster - a group of two or more parachutes that are attached to a single load and designed to open simultaneously.



Cone, Pack

cone, pack (locking cone) - a small, cone-shaped metal post sewn to one of the side flaps of the pack. A hole is drilled longitudinally through the cone a short distance from the top to admit the ripcord locking pin. Grommets of the opposing flap and the end tabs are placed over the cones and are held tightly in place by the insertion of ripcord pins in the holes provided.

construction, bias - a type of construction for drag producing surfaces in which the sections are cut and arranged in the gores so that the threads and section seams make an angle of other than 90° (usually 45°) to the centerlines of the gores. Bias construction is used for additional strength, and for the economy of material that can be achieved by cutting sections from standard width materials.

construction, block - a type of drag producing surface construction in which the sections are cut and arranged in the gores so that the warp threads and section seams make an angle of 90° to the centerline of the gore and are parallel to the skirt hem.

container, aerial delivery - a container designed for the purpose of dropping equipment and supplies by parachute from aircraft in flight. The container may be constructed of cotton, duck, metal, fiberglass, plywood, netting, or other suitable material, depending on the type, weight, and shape of the cargo to be delivered. The container may or may not incorporate a harness for transmitting forces developed during parachute canopy opening, and it may be carried on external racks or inside the aircraft.

cords. See lines, suspension.

cord, arming - a cord that pulls the firing wire out of a reefing line cutter, or other actuating device, thereby arming the device.

cushion, back - a pad attached to the inside of the harness of personnel parachutes to provide comfort for the wearer, and to hold the harness in place.

cutter, reefing line - a device designed to cut through the reefing line of a canopy. It normally incorporates a delay device (mechanical or pyrotechnical), a power device (mechanical or pyrotechnical), and an attached cutter.

damping - the reduction of induced oscillation of a parachute canopy during descent.

dart - a short, tapered seam.

deployment - that portion of a parachute's operation occurring from the initiation of ejection to the instant the lines are fully stretched, but prior to the inflation of the canopy.

deployment, bag - a method of canopy deployment utilizing a container, usually of fabric, for retaining the drag producing surface of the canopy until the suspension lines are deployed. This reduces the snatch force by allowing the acceleration of the canopy mass in small increments only. The lines may or may not be stowed on the bag, depending on the intended use. (See bag, deployment.)

deployment, (controlled) bag - a method of canopy deployment in which the deployment bag is attached to a static line and remains on the static line after the canopy is released.

deployment, (free) bag - a method of canopy deployment in which the deployment bag is attached to a pilot chute. When a static line is used to open a pack, the bag remains in the pack until it is removed by the pilot chute.

development - that portion of a parachute's operation occurring from the moment of initial canopy inflation, after completion of deployment, to the moment of full inflation of the canopy. Used synonymously with "inflation."

diameter, constructed - a designation of the size of a parachute canopy, based upon design dimensions.

diameter, nominal, D_o - the computed diameter designation of any design of parachute canopy, which equals the diameter of a circle having the same total area as the total cloth area of the drag producing surface. The total cloth area is based on the surface area and does include all opening in the drag producing surface, such as slots and vent. Since it refers to all canopies on a common basis, that is, surface area, this method of diameter designation is preferred for comparison of different designs of parachute canopy. For parachutes that have a vent area larger than 1% of the total area, the vent area is deducted from the total area (for example, airfoil parachutes). This term is not used for parachutes of the guide surface type.

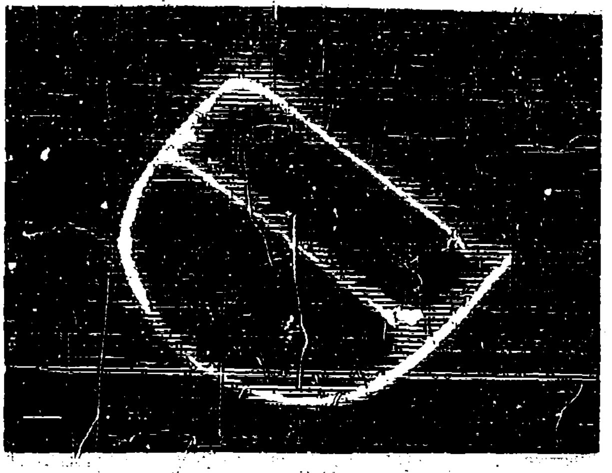
diameter, projected, D_p - the mean diameter of the inflated canopy, measured in the plane of the maximum cross section area. On canopies where the fabric curves out between the suspension lines, the projected diameter is the mean diameter of the inner and outer diameters.

disconnect, ground - a device that instantaneously releases the parachute canopy from the suspended load upon ground contact. This device may be actuated electrically, by the action of ground contact switches or "G" sensing devices; or it may be entirely mechanical and sensitive to canopy-load reduction.

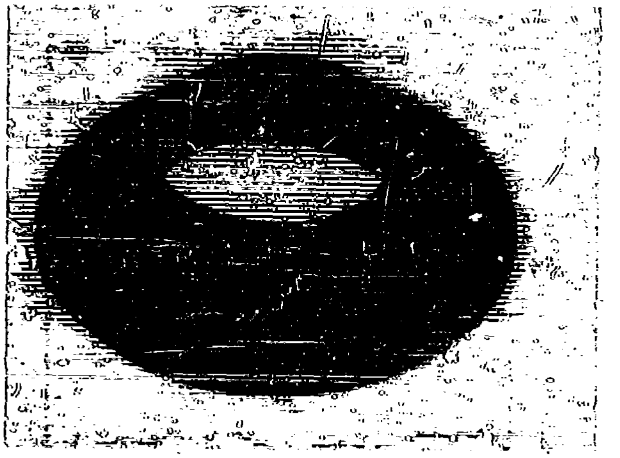
disreefing - the process of removing or changing the restrictive characteristics of a reefing system to increase the drag area of a parachute canopy. This may be accomplished in one step, in several stages, or continuously, until the canopy is fully inflated.

double-W - a type of reinforcing stitch in which one W is offset approximately 1/4 inch and superimposed upon another W.

drift - the horizontal displacement of the parachute canopy during descent. This may be caused by wind drift, or by the gliding of the parachute canopy.



D-Ring



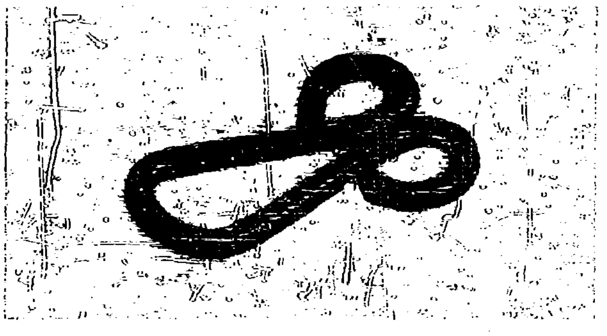
Eyelet, or Grommet

D-ring - a metal fitting shaped like a D into which snap connectors are hooked.

dummy, parachutes - torso-shaped dummy of variable weight used for testing parachutes. It may be of fixed or articulated construction.

elastics, flap removing. See elastics, pack opening.

elastics, pack opening - elastic cords, with a means of attachment at each end, installed on the pack under tension, used to separate the end flaps from the side flaps when the ripcord is pulled. These cords may be either rubber or metal springs.



Eye

eye - a small, steel-wire loop attached to the parachute pack, into which is fastened a hook on a pack-opening elastic.

eyelet - a small, metal reinforcement for a hole in fabrics, similar to a grommet, but thinner and smaller, and having no washer. The eyelet is used to reinforce lacing holes in small covers.

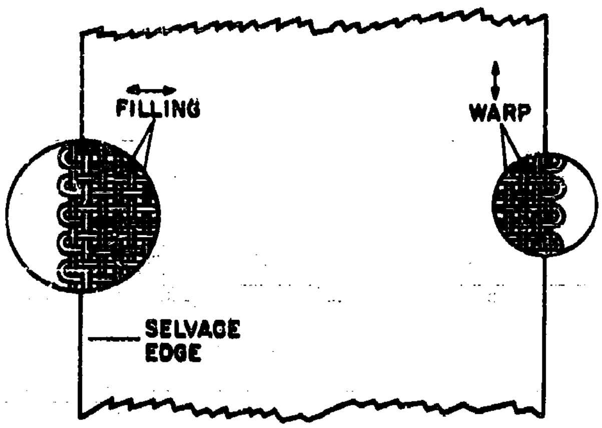
fastener, glove - a small, metal fastener consisting of button with socket and stud with eyelet.

fastener, "Lift-the-Dot" - a small, metal device made of four parts: the stud, the washer, the socket, and the clinch plate. When the stud is manufactured with a screw base, the washer is eliminated. "Lift-the-Dot" fasteners are made in several types of metal, with different stud lengths for use with the various weights of material. The term "Lift-the-Dot" indicates that the fastener is opened by lifting at one point only, that is, at a position beneath the small "dot" on the socket.

fastener, parachute pack - a metal fitting attached to a pack flap and designed to fit over a locking cone.

fastener, "Tri-lock" - a button-type fastener that provides for release in only one quadrant. It serves the same purpose as a "Lift-the-Dot" fastener, but it provides a smoother surface.

fid - a small, flat, tapered bar of metal or wood used during packing to insert the corner flaps into the pack.



Filling

filling - also called woof. These are the threads that run across the cloth as it comes from the loom. This term is not to be confused with "filling" in the sense of sizing, which means the addition of substances that give body or decreased porosity to the material.

FIST - abbreviated term used to designate narrow ribbon-type canopies. These canopies are characterized by gores constructed of ribbons, usually 2 inches in width, placed parallel to the skirt, with slots of predetermined dimensions between the ribbons. These canopies were first designed in Germany by Flugtechnisches Institut Der Technischen Hochschule Stuttgart.

flap, locking pin protector - a flap that covers the locking pins and cones to prevent the pack from being opened by any means other than pulling the ripcord.

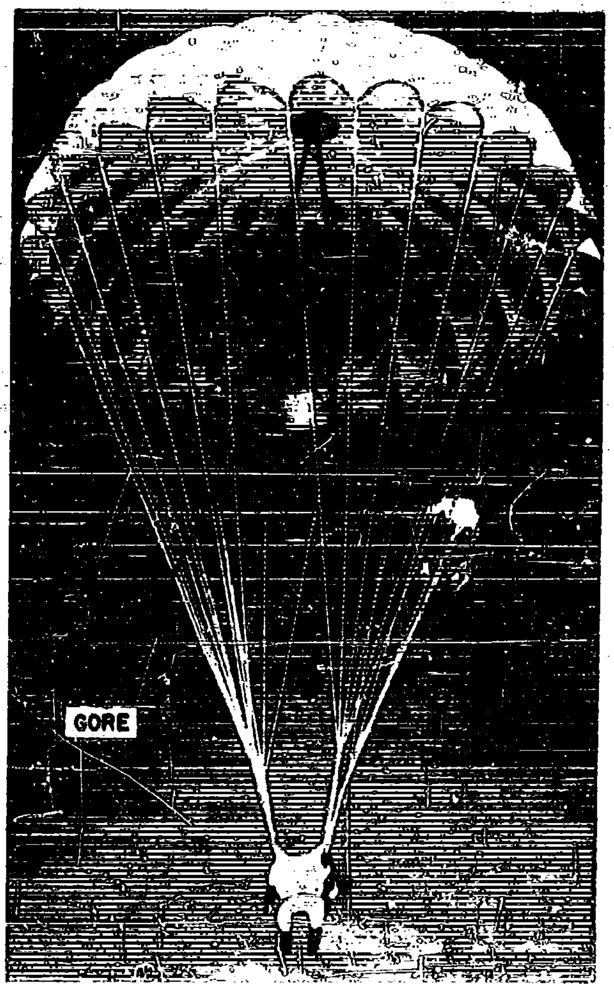
flap, pack - a fabric extension, on a side or end of the pack, designed to enclose and protect the canopy.

flaring - method of splitting, taping, and stitching the end of the webbing to widen it and prevent it from slipping through a fastener or adapter.

folding, accordion - folding a canopy into folds of uniform length, accordion fashion, before it is placed into the pack. A folding bar can be used to help make neat and properly spaced folds.

force, snatch - a force of short duration that is imposed by the sudden acceleration of the canopy mass at the instant of complete extension of the suspension lines or components of a parachute system prior to inflation of the canopy.

fortisan - a cellulose fabric that has great strength but very little elasticity.



Gore, Drag Producing Surface

gore - that portion of the drag producing surface contained between two adjacent suspension lines or radial seams.

grip. See handle, ripcord.

grommet - a metal eyelet and washer, used as a reinforcement around a hole in fabric. Grommets are used on pack flaps to fit over locking cones.

handle, ripcord - a metal loop designed to provide a grip for pulling locking pins from the locking cones of ripcord-actuated parachutes.

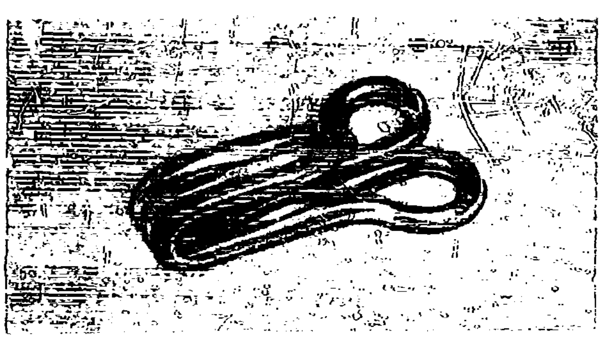
hardware - all metal fittings used on parachutes, parachute systems, and suspended loads.

harness - an arrangement of webbing, with metal fittings, designed to conform to the shape of the load in order to secure it properly, and to properly distribute the opening shock and the weight of the load.

hem - fabric folded back upon itself and sewed in this position to form both the peripheral edge and the vent of the canopy.

hesitator, skirt - a device that restricts the skirt of the drag producing surface, thus preventing inflation until the completion of the snatch force, at which time the hesitator line breaks and allows inflation of the canopy. This device reduces snatch force and canopy malfunctions.

hook, apex - a hook placed at the end of the packing table to position and hold the apex of the canopy to keep it under tension for packing or inspection.



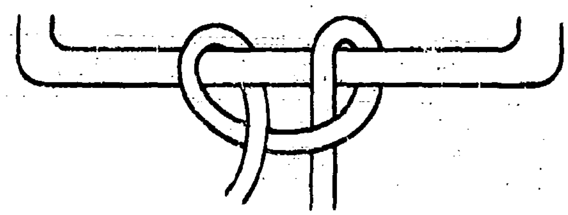
Hook, Pack-Opening Elastic

hook, pack-opening elastic - small, formed, steel-wire devices attached at both ends of pack-opening elastics. These are hooked in the eyes sewn on the pack.

housing, ripcord - a flexible metal tubing in which the ripcord cable is installed. The tubing protects the ripcord cable from snagging and provides a free path for it.

hook, stow - a packing tool consisting of a handle and a bent wire hook. It is used to pull the suspension lines into place in stow loops during packing of certain types of parachute canopies.

keepers, (pack, harness, suspension lines) - length of webbing sewed on a pack, or around suspension lines, and adjusted to hold the pack firmly to the harness or load on which it is used, or to form a confluence point for suspension lines to prevent relative movement of lines.



Knot, Clove Hitch

knot, clove hitch - a type of knot used for attaching the suspension lines of a canopy to the connector links.

legstrap - that part of the harness that passes under the wearer's leg and connects to the legstrap loop; or passes under the wearer's leg, through the strap loop, and to the harness release.

liftweb - that part of the harness comprising the main webbing support, extending from the connector links down through the saddle and up to the opposite connector links.

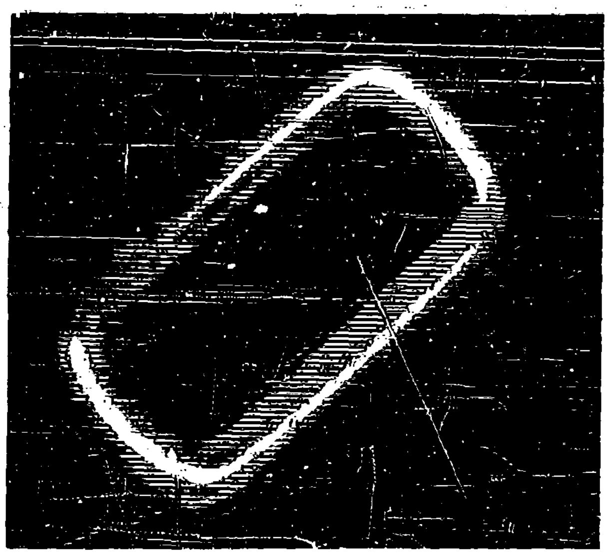
line, reefing - a length of cord or line passed through rings on the skirt of the drag producing surface to delay or control opening of the canopy.

line, static - a line, cable, or webbing, one end of which is fastened to the pack, canopy, or deployment bag, and the other to some part of the launching vehicle. It is used to open a pack or to deploy a canopy.

line, suspension - cords or webbings of silk, nylon, cotton, rayon, or other textile materials, that connect the drag producing surface of the canopy to the harness. They provide the means for suspension of the person or load from the inflated drag producing surface.

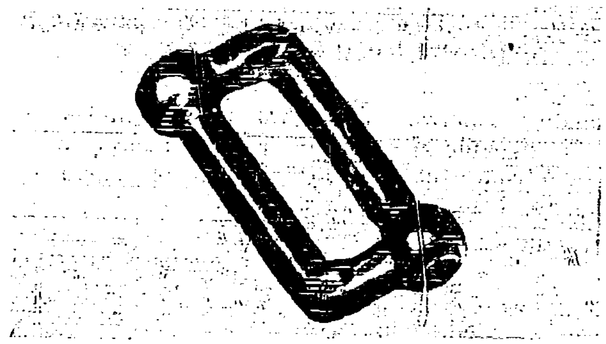
line-stowing - the process of drawing the suspension lines into suspension-line retaining loops in the parachute pack to prevent entanglement of the lines during opening of the canopy. Stows may be held by retaining loops or rubber bands, or may be tied to stowing straps.

lines, twisted suspension - a type of malfunction during canopy deployment caused by rotation of a suspended load, or pack, in relation to the position of the canopy. One full twist is defined as a 360-degree rotation. This method is also used to increase the opening time, and decrease the opening shock, of canopies used for drap parachute applications.



Link, Connector

link, connector - usually identified as a small, rectangular metal fitting used to connect ends of risers or lift webs to suspension lines. The suspension lines are tied and sewn about one part of the link, and the webs are stitched about the other part. The design of the link may vary in size and shape, according to the intended use.



Link, Connector, Separable

link, connector, separable - any connector link comprised of readily separable elements, which may be used to facilitate assembly of parachute canopies to a riser system.

loading, canopy - parachute canopy loading is defined as the ratio of the force transmitted from the canopy to the suspended load to the drag area of the canopy.

loop, retaining - loop of webbing or tape, usually elastic, used to hold folded lines or excess webbing in position.

loop, stow - webbing loop on deployment bag or pack designed to hold suspension lines in place on packed parachutes.

lug - a flat, metal fitting attached to the ends of harness webbing to provide attachment to the harness release.

malfunction - the complete or partial failure of a canopy to achieve proper opening and descent. Some causes of malfunction are high porosity, canopy damage, twisted suspension lines, improper packing or rigging, and improper or blanketed deployment.

mispick - a pick that failed to pass over or under the appropriate warp yarns during weaving.

opening, premature - any accidental opening of the canopy before the designated time of opening.

oscillation - the pendulum-like motion of a parachute suspended load during descent.

pack (pack assembly) term "pack" usually denotes the container alone. When so used, it is defined as a container that encloses the canopy and provides for a means of opening to allow deployment of the canopy. The canopy may or may not be placed in a deployment bag or sleeve.

pack cover - a piece of duck or canvas with static line attached, used to cover packed canopy in some types of pack assemblies.

pack end tab - a metal fitting secured to each end flap of a pack. The end tabs fit over locking cones and secure the end flaps in a closed position until the locking pins are pulled.

pack flap - a fabric extension on a side or end of the pack body designed to enclose and protect the canopy.

pack frame - a rigid or flexible frame used to maintain desired pack shape.

paddle - a flat, narrow piece of wood used for dressing the parachute pack and for stowing certain webbings or flaps in retainers.

palm, sewing - a hand protector used in heavy hand sewing to direct the needle through heavy material.

parachute - an assembly consisting of canopy, risers, or bridles, deployment bag, and, in some cases, a pilot chute. The pack and attaching webbings (harness) are considered a part of the parachute when they are not built into the suspended load as an integral part.

parachute, aerial delivery - a parachute designed to deliver equipment and supplies from an aircraft in flight. It is used synonymously with the term "cargo chute."

parachute, approach, landing - a parachute used in flight to improve jet aircraft flight characteristics during normal landing approach, or in approach under marginal weather conditions.

parachute, attached type - a parachute, the pack of which is so attached to an aircraft that the canopy deploys from the pack as the load falls away.

parachute, back type - a parachute designed to be worn on a wearer's back and shoulders.

parachute, chest type - a parachute designed for attachment to the wearer's chest.

parachute, deceleration, landing - a parachute used generally on jet aircraft to decrease aircraft landing roll. "Parachute, drag," is used as an alternate term.

parachute, extraction - a parachute used to extract cargo from aircraft in flight, and to deploy cargo parachutes.

parachute, first stage - a parachute used to decelerate and stabilize a falling object so that either the intermediate or the final recovery parachute can be safely deployed. This term applies only to parachute recovery systems. The terms drogue and parabrake may be used also; however, the use of these terms is being discouraged.

parachute, free type - a parachute, not attached to an aircraft, that is operated by the jumper at his discretion.

parachute, intermediate - a parachute that has the purpose of further decelerating an object, after the first stage parachute has been disconnected, to a speed at which it is safe to deploy the final recovery parachute. This term applies only to parachute recovery systems.

parachute, personnel - a parachute used to lower personnel from aircraft in flight.

parachute, reserve - a second parachute, usually worn on the chest of personnel making a premeditated jump. It is used in the event of malfunction of the main parachute.

parachute, stabilization-brake - a parachute used to maintain, or to make it possible to maintain, the attitude of a falling body, and to retard its fall.

parachute, static line type - a parachute in which deployment of the canopy is initiated by means of a static line attached to an aircraft. Both "troop type" and some "aerial delivery type" parachutes may be placed in this category.

parachute, troop type - a parachute used primarily by paratroopers for a premeditated jump over a designated area.

parachute rotation - the turning of a parachute canopy about its vertical axis during descent.

peak. See apex.

permeability - a term used to designate the measured volume of air in cubic feet that will flow through one square foot of cloth in one minute at a given pressure. In the United States, permeability is measured by using a pressure of one-half inch of water. In Great Britain, 10 inches of water pressure is used.

pick - an individual filling yarn in webbing or fabric.

Pilot Chute

pilot chute - a small parachute used to accelerate deployment. It is constructed in much the same manner as the main canopy, from similar material. Some types of pilot chutes are equipped with a spring operated, quick opening device. The frame is so compressed that it will open immediately when it is released from the pack.

pin, clevis - a metal rod, which is fitted with a cotter pin or is threaded, then inserted through holes in the end of the clevis to close its open end.

Pin, Locking

pin, locking - short, metal prongs attached to a ripcord cable. Locking pins are inserted into locking cones to secure the pack flaps as a function of closing a parachute pack.

pin, ripcord. See pin, locking.

platform - a base of metal and wood that serves as the support on which equipment may be loaded for aerial delivery purposes.

pocket, log record - a small patch pocket sewed to a part of the parachute, usually the pack, for carrying the parachute packing record card.

porosity - the ratio of open space to covered area of the drag producing surface. (Used for Ribbon, Ringslot, and Rotofoil type canopies.)

rate of descent - the vertical velocity, in feet per second, of a fully opened parachute canopy.

recovery system, parachute - a parachute recovery system includes all items that are required to recover an object from flight and to land it safely on the ground or on water with a minimum of damage. In general, the following subsystems are included: first stage, intermediate, and final recovery parachutes; controlling devices; actuating devices; and landing or flotation devices, or both.

reefing, skirt - a restriction of the skirt of a drag producing surface to a diameter less than the diameter when it is fully inflated. Reefing is used to decrease the opening shock, to decrease drag area, and to obtain stability.

release, canopy - a device that is designed to permit rapid separation of canopy and risers from the suspended load.

release, harness - a manually operated device incorporated in a harness. It is designed to permit the rapid release of the harness from the wearer.

repairs, minor - any repairs required to return the parachute to perfect condition, but which, if not made, will not seriously affect its performance or airworthiness.

rings, reefing - metal rings attached to the skirt of a drag producing surface at the suspension line connection points through which a reefing line is passed. These rings are designed to eliminate any hinging action in the ring, with consequent binding of the reefing line.

ripcord - a locking device, consisting of cable, locking pins, and grip, that secures the pack in a closed condition. It effects the release of the canopy.

riser - that portion of the suspension system between the lower end of a group of suspension lines or canopies and the point of attachment to the load. Since it must be as strong as the total strength of all suspension lines attached thereto, it usually is fabricated from high-strength material, such as webbing, or, in some cases, steel cables.

saddle - the part of the harness that is positioned in the main lift web at the seat of wearer and widened and reinforced to provide a seat or sling for the wearer.

Sail

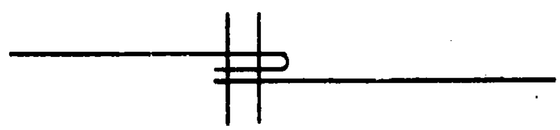
sail - a term used to designate a condition noted in the deployment of a parachute canopy when the canopy, just after leaving its pack but still attached to a static line, is exposed broadside to the airstream and temporarily assumes a shape similar to a sail. When using a deployment bag, the same condition may occur when the suspension lines have extended but the drag producing surface is still in the deployment bag.

seam - the fold or line formed by the sewing together of two pieces of material.

seam, bias - the radial or diametral seam of a bias constructed drag producing surface.

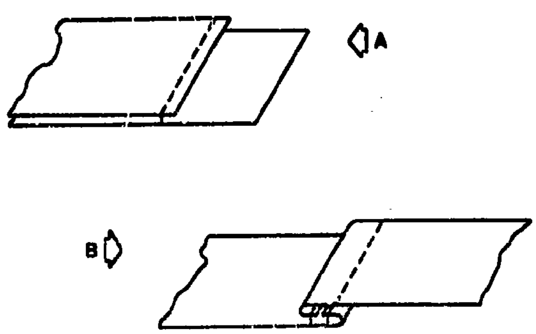
seam, block - a seam that runs parallel to the warp, or filling threads, of material used in block construction of drag producing surfaces.

seam, diagonal - the diagonal or horizontal seams that join the sections of each gore of a bias constructed drag producing surface.



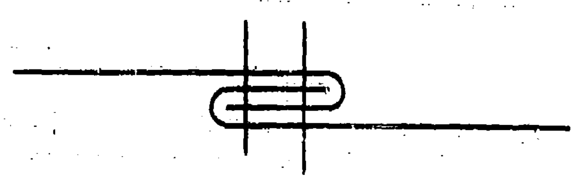
Seam, English Fell

seam, English fell - a type of seam in which one piece of material is folded back on itself and the other piece is a plain overlap.



Seam, Folded Fell

seam, folded fell - in forming this type of seam, the plies of material are first joined as shown in (a). The one ply is then turned back, the edge of the other ply is turned, and the two plies are sewed with a second row of stitching, as shown in (b).



Seam, French Fell

seam, French fell - this type of seam is formed by turning the edges of both plies of the material, lapping them as shown in the sketch, and sewing with two (or more) rows of stitches, which also secures the turned positions.

seam, radial - a seam that extends from the skirt to the vent and joins two gores. A portion of the suspension lines may be concealed in the tubes formed by the radial seams.

searing - method of sealing ends of nylon cord or webbing by melting them to prevent raveling.

section - any one of the pieces of cloth which, when assembled, form one gore of a drag producing surface.

selvage - the woven edge of cloth.

separator, line - a slotted metal or wood device used to hold suspension lines at the canopy skirt after separation into groups during packing.

serving - a method of wrapping or binding the ends of cord or line so they will not unravel, or to provide protection for loops. It is also referred to as whipping. Served loops are sometimes used to replace connector links at the load end of the suspension lines. The latter construction, however, makes maintenance costly and difficult.

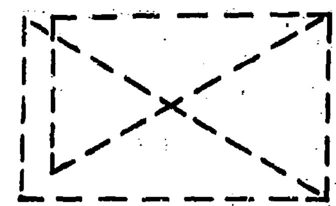
shock, deployment. See force, snatch.

shock, landing - the force imposed upon the suspended load at ground impact.

shock, opening - the maximum force developed during inflation of the canopy.

shoulder strap - that part of the harness which crosses the wearer's shoulder.

shot bag - a parachute packing tool. A rectangular duck bag is filled with sand or shot and used to hold folded gores in position during packing.



Single-x Stitch

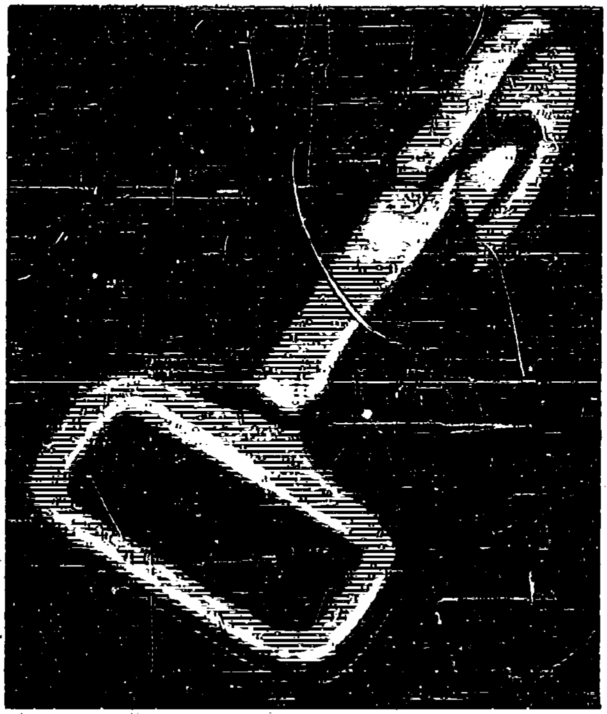
single-x - a stitch pattern representing an X-formation, usually used with a boxstitch.

skirt - the reinforced hem forming the periphery of a drag producing surface.

sleeve - a tapered, fabric tube in which a canopy is placed to control its deployment.

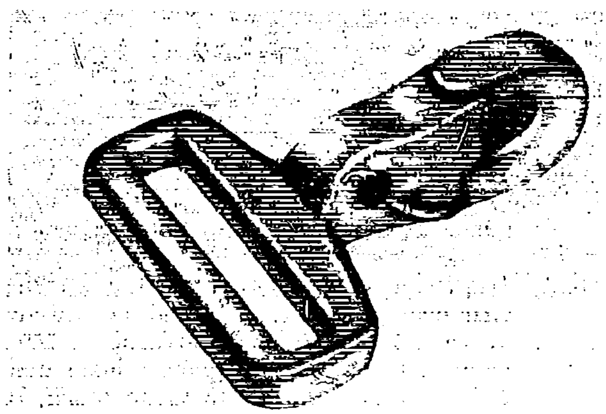
slipping, controlled - a method of guiding an inflated canopy in a desired direction by spilling the air from one side of the skirt by manipulation of the suspension lines. This action causes an increased average rate of descent until the lines are released.

slot - a vent within a gore of a drag producing surface. The size of the slot will determine or control the geometric porosity of certain canopy designs.



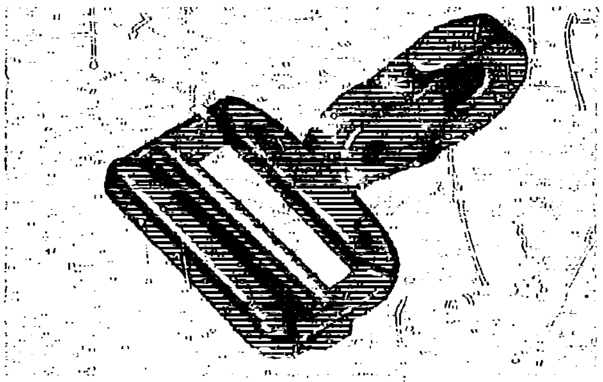
Snap, Connector, Quick

snap, connector, quick - a hook shaped, spring loaded metal fitting that snaps over a D-ring to connect two webbings.



Snap, Harness

snap, harness - a hook shaped, spring guarded metal fastener that snaps over a V- or D-ring to secure two parts of an assembly.



Snap, Harness, Friction

snap, harness, friction - a sliding grip friction buckle with a metal snap attached to a parachute harness to secure two parts of the harness together, and also to permit quick fit adjustments on the wearer or load.

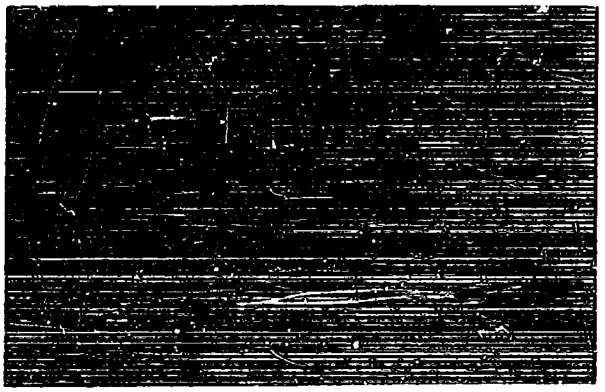
snap, static-line - a metal device used to connect the free end of a static line to a cable or ring in an aircraft.

speed, opening, critical - the speed during deceleration at which a canopy in the squid form assumes normal inflation, but above which it will not fully inflate.

speed, sinking. See rate of descent.

spike, recovery - a pointed beam extension on the nose of the load that absorbs ground impact energy by penetrating the ground.

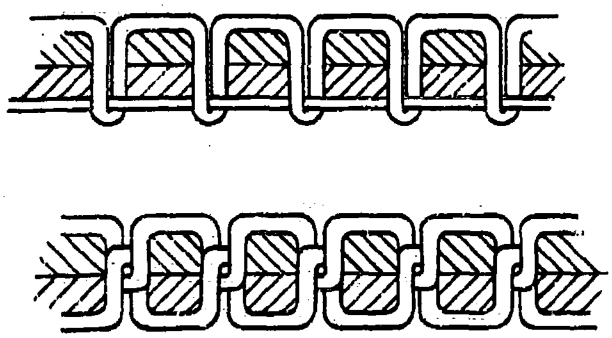
squidding - a state of incomplete parachute canopy inflation in which the canopy has a pear-like shape. Squidding occurs if the canopy is deployed above a critical speed.



Squid Shape

squid shape. See illustration.

stiffener, pack - rectangular strips of metal or fiber placed in the pack flaps to stiffen the flaps. These strips are also used for shaping the sides and bottom of packs.



Stitch, Lock

stitch, lock - a nonraveling stitch used to form a seam.

stitching, bunched - a defective seam resulting from a higher concentration of stitches per inch than is required.

stitch, box - a rectangular or square stitch pattern, generally used to enclose a single-x or triple-x stitch formation.

stitch, chain - ornamental, basting, or seam stitch in which thread, or threads, is not interlocked but is held by a loop of needle thread or a loop of bobbin thread. There may be single-, double-, or triple-thread chain stitching.

stitch, double throw - zigzag stitching in which the needle makes a center stitch between each left and right stitch.

stitch, four-needle - a method of stitching that can be performed in one operation by a four-needle sewing machine. It is used in sewing the top hem, the circumferential hem, and the radial seams of a drag producing surface.

stitch, single throw - zigzag stitching in which the needles travel completely from one side to the other between stitches.

stitching, zigzag - stitching done by a sewing machine that makes stitches alternately on two or more parallel lines. It is used to reinforce and anchor the suspension lines to the drag producing surface.

stow - any one loop of static line or suspension line compactly secured to the parachute pack.

streamer - a malfunction in which a parachute canopy stretches full length during descent without reaching squid shape.

strength, tear - the average force, measured in pounds, required for a continuous tear across either the filling or the warp of a fabric.

strength, tensile - the tension, measured in pounds, required to break a material. The tensile strength of a fabric is stated in pounds per inch width for warp and for filling. The tensile strength of webbings and tapes is stated for the full width, such as 250-lb. tape.

surface, drag-producing - that portion of a parachute canopy consisting of the cloth area designed to produce the desired drag.

swage - to join metal parts by pressure, such as in attaching ripcord locking pins to ripcord cable.

tacking - a slight sewing, usually by hand, with long stitches as in basting, but usually concentrated in a certain area or around a certain part.

tape, reinforcement - tape or webbing sewed to the pack or canopy to strengthen the fabric at a weak spot or point of stress.

test, drop - a test to determine the working efficiency of a parachute and its systems by releasing it from an aircraft or from some height above the ground under conditions very similar to those found, or anticipated, in normal operation.

tie-down - a chain and binder assembly used to lash cargo to tie-down rings in aircraft or to heavy drop platforms.

time, filling - the time elapsed between the full extension of the canopy and the opening of the canopy to its fullest extent.

time, opening - the elapsed time between the opening of a parachute pack and the opening of the canopy to its fullest extent.

thread, break - a stitching intended to break easily under a relatively small stress. In certain types of packs, for example, a break thread is used to fasten the lift webs inside the pack. This thread breaks during the deployment or opening of the canopy.

tower, drying - a facility where parachutes are suspended for drying and airing.

triple-x - a stitch pattern resembling three adjoining X's. It is often used with a boxstitch.

tuck - a shortening of material caused by pulling fabric up in folds and stitching across the gathered fabric.

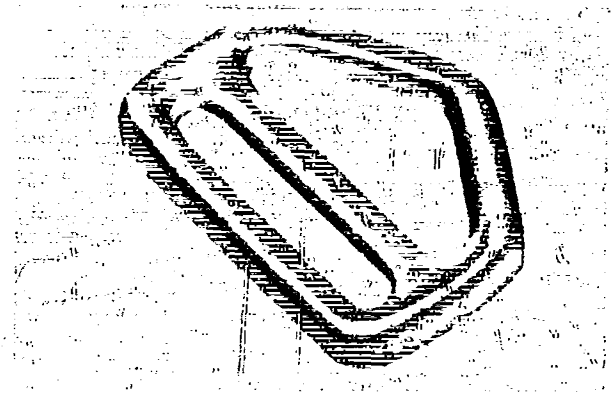
twist, suspension lines - the twisting of each group of suspension lines separately, usually caused by rotation of the pack or harness between the two groups.

underfold - a fold in which insufficient material has been folded inside the seam, usually resulting in exposed raw edges.

velocity, equilibrium - the velocity that a falling body can attain when the drag is equal to the weight, i.e., the acceleration equals zero.

vent - any opening in the cloth surface of the canopy for the purpose of air venting. Specifically, the opening at the top, or center, of the drag producing surface.

vent, puckered - a cloth sleeve or collar attached to and encircling the vent, puckered by the use of an elastic member that is tightly drawn at the apex of the vent.



V-Ring

V-ring - a metal fitting in the form of a closed letter V that is used with snaps to secure or attach a load to a canopy.

v-tap - a short length of tape or webbing wrapped tightly around a suspension line and stitched to the skirt hem.

warp - the threads that run parallel to the selvage edge of cloth; those threads that are crossed by the filling threads, also called weft. (For sketch, see threads, filling.)

wax, paraffin - wax generally used with 50% beeswax as a hot dip to prevent the fraying of cut ends of webbing, cord, and tape.

web, lift. See riser.

webbing. See harness.

CHAPTER I

SECTION 2

STANDARD SYMBOLS

2.1 PRIMARY CONCEPTS.

A	A dimensionless factor used in the approximation of velocity decrease during filling time
A_{VR}	Vertical ribbon width (in.)
AR	Aspect ratio
a	Acceleration (ft. per sec^2)
a_S	Speed of sound in air (knots)
a_{VR}	Distance between vertical ribbons (in.)
B_{HR}	Horizontal ribbon width (in.)
b_{HR}	Distance between horizontal ribbons (in.)
C	Coefficient (general)
c	Factor related to suspension line convergence angle
c_D	Drag coefficient (general)
c_{D_A}	Drag coefficient of aircraft
c_{D_B}	Drag coefficient of suspended load
c_{D_o}	Drag coefficient of parachute canopy based on total cloth area, S_o, and vertical descent velocity
$c_{D_{or}}$	Drag coefficient of parachute canopy based on total cloth area and resultant velocity
c_{D_p}	Drag coefficient of parachute canopy based on inflated (projected) canopy area
$c_{L_{TD}}$	Lift coefficient of aircraft at touchdown
c_M	Moment coefficient (general)
c_o	Effective Porosity
c_r	D_R/D_c = ratio of reefing diameter to flat (constructed) canopy diameter
c_T	Tangential force coefficient (general)
D	Drag (general) (lb.)
D_c	Diameter, constructed (ft.)
D_l	Constructed diameter of the reefed parachute canopy measured at the inside of the skirt (ft.)
D_o	Nominal canopy diameter $= \sqrt{\frac{4\ S_o}{\pi}}$ (ft.)
D_p	Projected or inflated canopy diameter (maximum inflated diameter) (ft.)
D_{p_i}	Instantaneous projected canopy diameter (ft.)
D_{p_l}	Projected diameter of the reefed canopy (ft.)
D_R	Diameter of a circle formed by the points of suspension line connection to the skirt of a reefed parachute canopy (ft.)
D_S	Diameter of a circle formed by the points of suspension line connection to the skirt of a fully inflated parachute canopy (ft.)
d	Distance (general) (ft.)
d_v	Vent diameter (ft.)
E	Energy (ft.-lb.)
e	Factor related to strength loss by abrasion
e_g	Base width of gore (in.)
e_{g_v}	Gore width at vent (in.)
F	Force (general) (lb.)
F_c	Constant force on fully inflated canopy (lb.)

F_d	Drag force of canopy as transmitted to suspended load (lb.)
F_N	Normal force (general) (lb.)
F_o	Peak opening shock force (lb.)
F_S	Peak snatch force (lb.)
F_T	Tangential force (lb.)
F_W	Crosswind force (lb.)
f	Cyclic frequency (cps)
g	Acceleration due to gravity (ft. per sec^2) (32.2 at sea level)
h	Height or altitude (ft.)
h_a	Actual constructed height of gore (in.)
h_g	Height of gore (in.)
i	Specific impulse (lb. per sec per unit)
j	Safety Factor
I	Mass moment of inertia (slugs per ft.^{2})
K	A dimensionless factor used in the determination of opening shock
k	Factor related to strength loss by fatigue
k_b	Drag loading of the suspended load (ft.$^{-1}$)
k_p	Drag loading of the uninflated parachute canopy (ft.$^{-1}$)
L	Lift (general) (lb.)
L_a	Length of pocket band (in.)
L_b	Length of intercept on the skirt (pocketband) (in.)
l	Length or distance (general) (ft.)
l_b	Constant for pocketbands ($l_b = 0.14$)
l_s	Length of suspension line from canopy skirt (ft.) to suspension line confluence point
M	Moment (general)
m	Mass (slugs)
N	Revolutions per minute (rpm)
N_M	Mach Number $= \frac{v}{a_s}$
n	Dimensionless factor used in the determination of canopy filling time
n_f	Load factor
n_g	Number of gores
o	Factor related to strength loss in material from water and water vapor absorption
P	Momentary tension force in the suspension lines (lb.)
P	Force (lb.)
P_{max}	Maximum force (lb.)
p	Pressure (general) (lb. per ft.^{2})
q	Dynamic pressure assuming incompressible fluid (lb. per ft.^{2})
q_d	Impact pressure corresponding to the velocity at peak opening shock force (lb. per ft.^{2})
q_s	Impact pressure corresponding to the velocity at peak snatch force (lb. per ft.^{2})
R_e	Reynolds number
r	Radius (general) (ft.)
r_b	Radius of circular arc between two main seams of a drag producing surface (ft.)
r_v	Vent radius (in.)
S	Area (general) (ft.^{2})
S_A	Wing area of aircraft (ft.^{2})
S_B	Cross-sectional area of suspended load (ft.^{2}) corresponding to c_{D_B}
S_g	Total area of openings in a parachute canopy (ft.^{2})
S_o	Total cloth area of a canopy, or design surface area including slots and vent (vent not included if larger than 0.01 S_o) (ft.^{2})
S_p	Projected area of inflated canopy (ft.^{2})
S_{RR}	Total area covered by radial ribbons (ft.^{2})
S_{VR}	Total area of horizontal ribbons at the vent, not covered by radial ribbons (ft.^{2})
S_λ	Total slot area of Ringslot Parachute Canopy (ft.^{2})
s	True distance along curve (ft.)
s_o	Area of vent (ft.^{2})
T^o	Temperature (°F.)

T_h	Circumferential tension on canopy fabric (lb.)
T_r	Radial tension on canopy fabric (lb.)
t	Time, general (sec)
t_d	Deployment time from release to completion of canopy line stretch (sec)
t_f	Time interval from occurrence of peak snatch force to the instant when parachute canopy is inflated to maximum projected diameter (filling time) (sec)
t_{s_o}	Time interval from occurrence of peak snatch force to occurrence of peak opening shock (sec)
$t_{r_{1,2,3}}$	Reefing time (sec)
u	Factor involving the strength loss at the connection of suspension line and drag producing surface or riser respectively
V	Volume (general) (cu. in.)
V_p	Volume of the parachute canopy (cu. in.)
v	Resultant velocity (ft. per sec)
V_d	Velocity at instant parachute canopy is deployed (ft. per sec)
v_e	Equilibrium velocity at altitude (ft. per sec)
v_{e_o}	Equilibrium velocity at sea level density (ft. per sec)
v_i	Velocity after time t (instantaneous) (ft. per sec)
v_o	Launching speed (ft. per sec)
v_s	Velocity at instant of full line stretch (ft. per sec)
W	Weight, general (lb.)
W_A	Gross weight of aircraft at touchdown (lb.)
W_b	Weight of suspended load (lb.)
W_c	Weight of canopy cloth area (including weight of suspension lines across the cloth area, but not including weight of free length of suspension lines) (lb.)
W_l	Weight of suspension lines (lb.)
W_p	Weight of parachute canopy (lb.)
W_t	Total weight (lb.)
w	Unit weight (general) (lb. per unit length)
w_c	Unit weight of fabric (oz. per yd.^{2})
w_l	Unit weight of suspension lines (oz. per 10 yd.)
w_u	Unit loading (lb. per ft.^{2})
X	Opening shock factor which denotes a relationship between peak opening shock force F_o, and constant force, F_c, at equivalent velocity
x	Coordinate along X-axis
y	Coordinate along Y-axis
z	Coordinate along Z-axis
z	Number of horizontal ribbons
z_R	Number of individual riser webbings
Z	Number of suspension lines
α	Angle of attach (degrees)
β	Gore vertex angle (degrees)
γ	Specific weight of dry air (lb. per ft.^{3})
γ_s	Suspension line confluence angle (degrees)
Δ	Small increment (not used alone)
ϵ	Elongation
η	Efficiency
η_w	Drag efficiency (based on canopy weight) (lb. per ft.^{2})
η_v	Drag efficiency (based on canopy volume) (cu. in. per ft.^{2})
λ_a	Porosity correction (percent)
$\lambda_{act.}$	Actual geometric canopy porosity (percent)
λ_g	Geometric canopy porosity (percent)
λ_{g_g}	Ribbon grid porosity (percent)
λ_n	Mechanical (cloth or webbing) porosity (percent)
λ_t	Total canopy porosity (percent)
ν	Kinematic viscosity (ft.^{2} sec)
ν_a	Absolute viscosity (lb. per sec per ft.^{2})

π_0	Polygon shape factor
δ	Density of air at a given altitude (slugs per cu. ft.)
δ_0	Density of air at sea level (0.00238) (slugs per cu. ft.)
σ	Density Ratio = $\frac{\delta}{\delta_0}$
ϕ	Angle of oscillation, angle of displacement (degrees)
ρ	Angle between opposite suspension lines (degrees)
ω	Angular velocity (radius per sec)

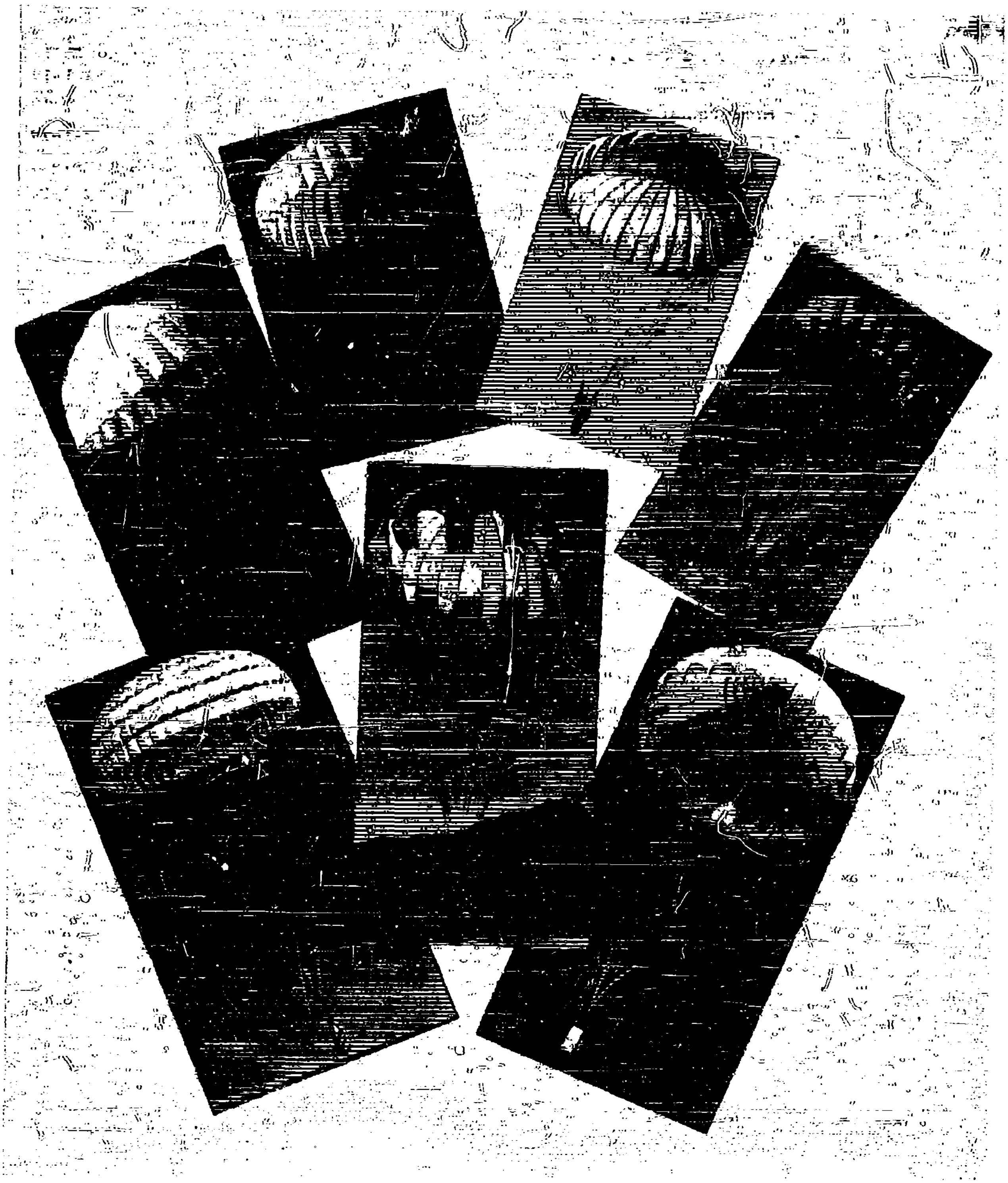
2.2 SECONDARY CONCEPTS (TO BE USED AS SUBSCRIPTS AND SECONDARY SUBSCRIPTS).

a	Added; additional; absolute
av	Average
c	Canopy; critical; constant
cp	Center of pressure
cg	Center of gravity
d	Deployment
D	Drag
e	Equilibrium; exit
f	Pertaining to filling process; fill of cloth; fabric; skin friction
g	Geometric
h	Horizontal or hoop direction
i	Pertaining to inlet
I	Instantaneous
l	Referring to reefed condition
L	Lift; load
m	Material
M	Moment
N	Normal
o	Total cloth area; opening; reference condition
p	Projected
rb	Reinforcing band
r	Resultant; radial
s	Skirt; referring to snatch force; suspension lines
sq	Squidding
SL	Sea level
t	Tangential
T	Total
th	Theoretical
v	Vertical; vent
w	Wind
X	X-direction component
Y	Y-direction component
Z	Z-direction component

CHAPTER II

PARACHUTES AND PARACHUTE SYSTEMS, GENERAL

TABLE OF CONTENTS



Frontispiece. Composite of Various Canopy Types

CHAPTER II

SECTION 1

TYPES OF PARACHUTE CANOPIES

1.1 GENERAL.

1.1.1 The parachute constitutes those components which, functioning together, provide a means for controlled descent, deceleration, or stabilization of a mass. The system must provide for deployment of the parachute, support for the loads, required drag characteristics, and, in some cases, automatic detachment of canopy and load.

1.1.2 Generally, the first considerations for design of the parachute system are those of the required drag characteristics. The drag characteristics are almost wholly controlled by canopy configuration.

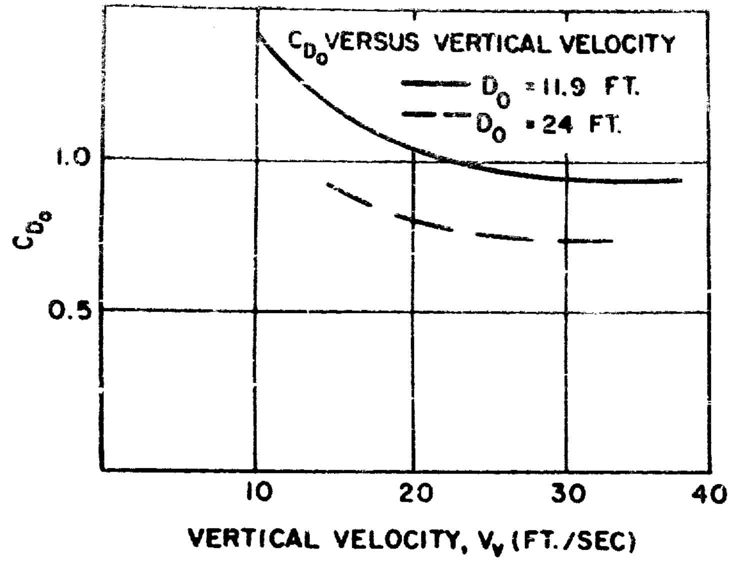
1.1.3 A secondary consideration, but not necessarily of secondary importance, is the design of the deployment system, shock reduction systems, and hardware.

1.1.4 Many varied geometrical canopy shapes have been investigated in the course of the Parachute Development and Research Program. Since almost all of the conceivable shapes might be applied for the design of parachute canopies, it becomes virtually impossible to conduct a complete study of each possible variation. The designs and shapes discussed in the following paragraphs represent those that have undergone sufficient investigation to establish some definite characteristics in behavior and are most commonly used in general parachute applications.

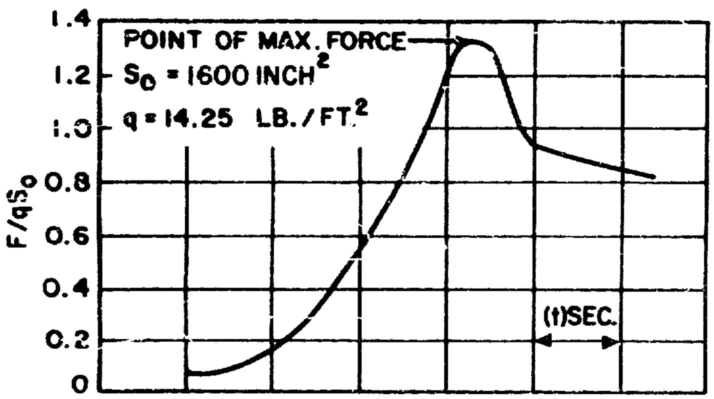
1.1.5 In all cases except the ribbed and ribless type guide surface parachute canopies, canopy diameter as referred to hereafter is the "nominal diameter D_o." For ribbed and ribless type guide surface parachute canopies, the "constructed diameter D" is commonly used, which is equivalent, in these cases, to the "inflated diameter D_p."

1.1.6 Drag coefficients as presented hereafter are based upon the area S_o in all cases except for ribbed and ribless type guide surface parachute canopies. The symbol for this drag coefficient is c_{D_o}. For ribbed and ribless type guide surface parachute canopies, the drag coefficient is based upon the area S. For these parachute canopy types, the symbol for the drag coefficient is c_D.

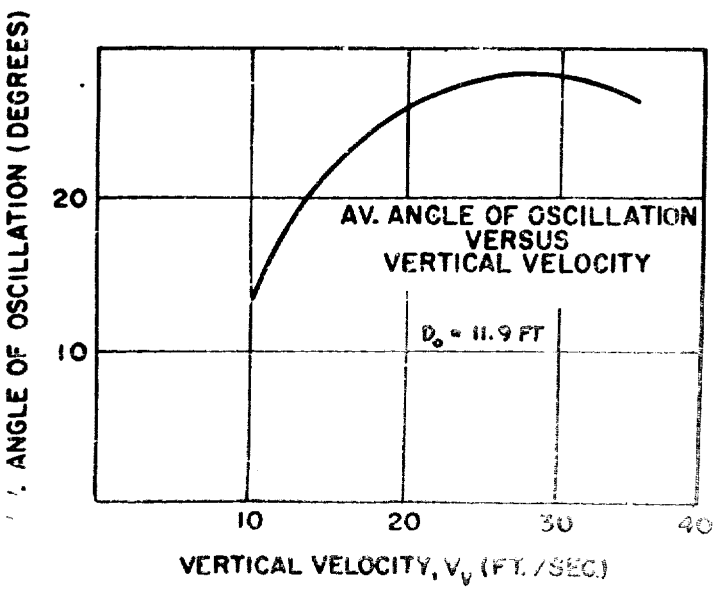
1.1.7 Data presented on the following graphs are intended for comparative purposes of different canopy designs only. The c_{D_o}, F/qS_o, and average angle of oscillation values presented are peculiar only to the canopy design and size stated. At present, no accurate relationship between model and full-size parachute canopies can be established. For additional values of performance and design characteristics of larger size canopies, refer to Chapter III, Parachute Applications, and Chapter V, Parachute Design Details. All values listed in the following paragraphs refer to subsonic applications and sea-level density.



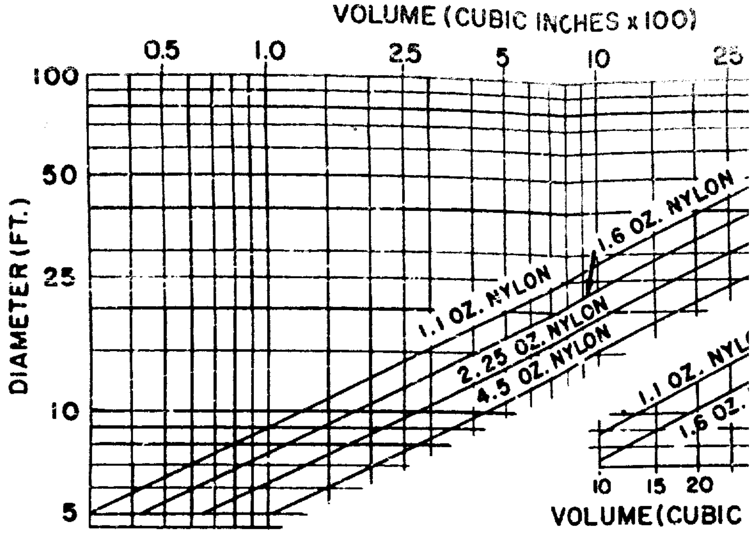
C_{D_0} VERSUS VERTICAL VELOCITY
D_0 = 11.9 FT.
D_0 = 24 FT.
C_{D_0}
1.0
0.5
10
20
30
40
VERTICAL VELOCITY, V_v (FT./SEC)



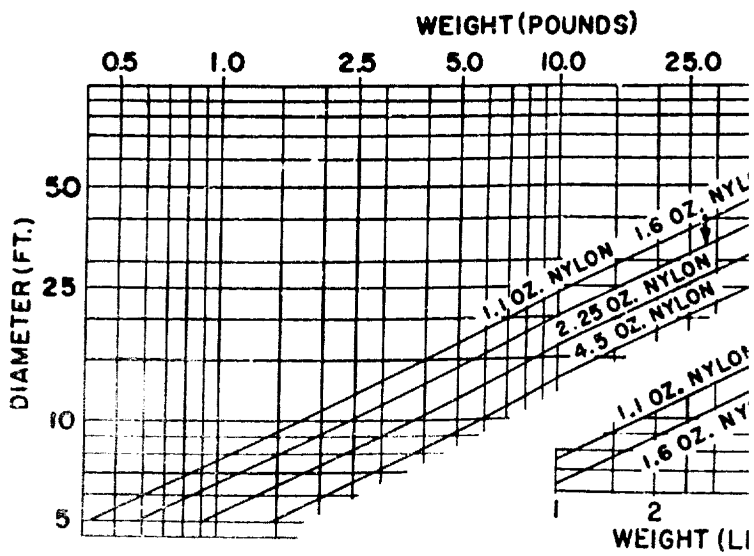
POINT OF MAX. FORCE
S_0 = 1600 INCH^2
q = 14.25 LB./FT.^{2}
F/qS_0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
(t)SEC.



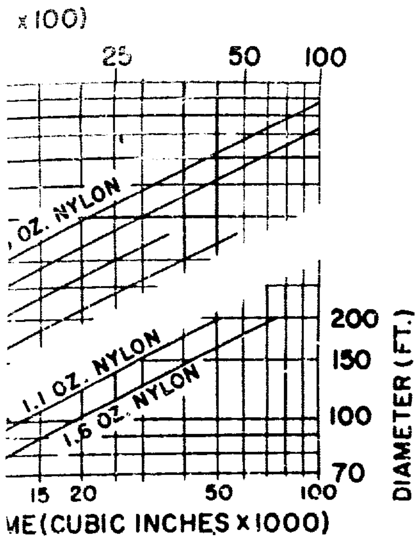
AV. ANGLE OF OSCILLATION (DEGREES)
AV. ANGLE OF OSCILLATION
VERSUS
VERTICAL VELOCITY
D_o = 11.9 FT
20
10
10
20
30
40
VERTICAL VELOCITY, V_v (FT./SEC.)

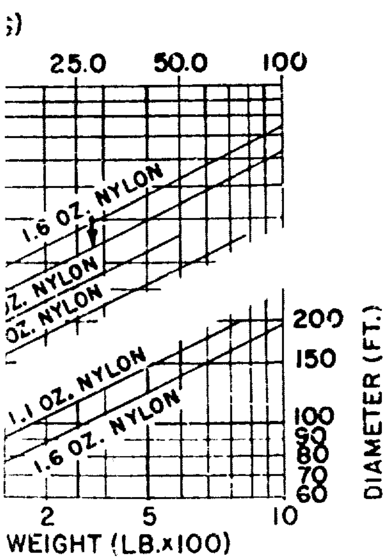


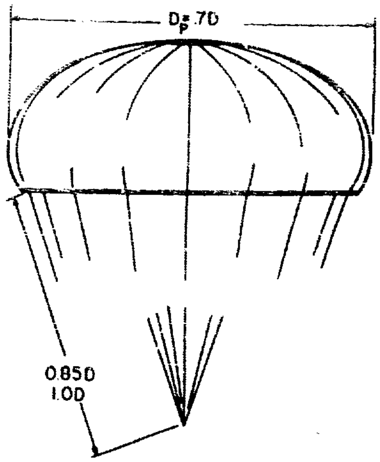
VOLUME (CUBIC INCHES x 100)
0.5
1.0
2.5
5
10
25
DIAMETER (FT.)
100
50
25
10
5
1.1 OZ. NYLON
1.6 OZ. NYLON
2.25 OZ. NYLON
4.5 OZ. NYLON
10
15
20
VOLUME (CUBIC

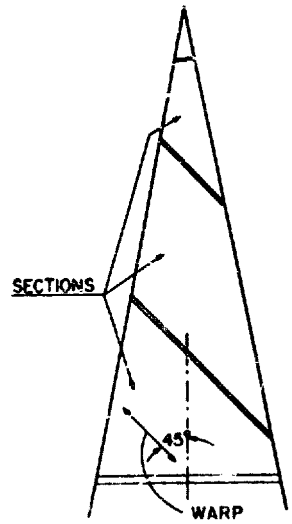


WEIGHT (POUNDS)
0.5
1.0
2.5
5.0
10.0
25.0
DIAMETER (FT.)
50
25
10
5
1.1 OZ. NYLON
1.6 OZ. NYL
2.25 OZ. NYLON
4.5 OZ. NYLON
1
2
WEIGHT (LI









TYPICAL GORE

1.2 SOLID TEXTILE PARACHUTE CANOPIES.

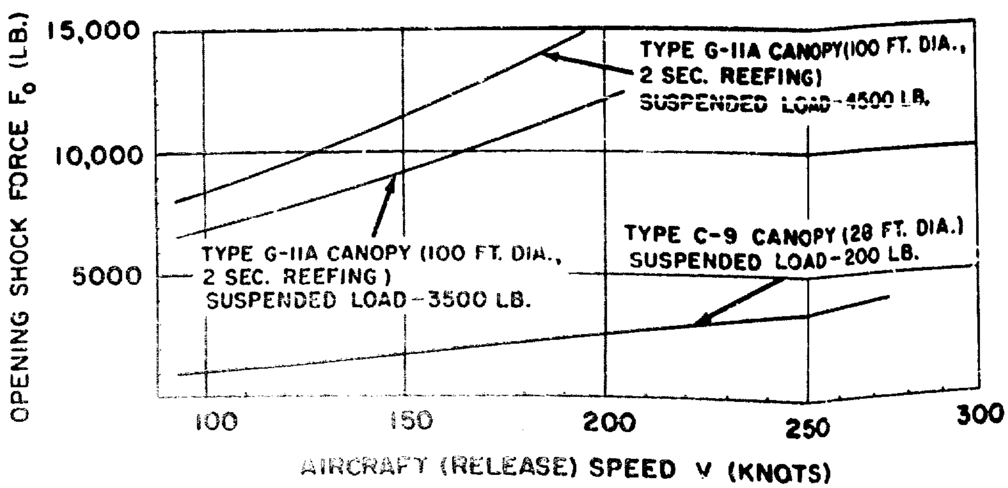
1.2.1 FLAT CIRCULAR CANOPY.

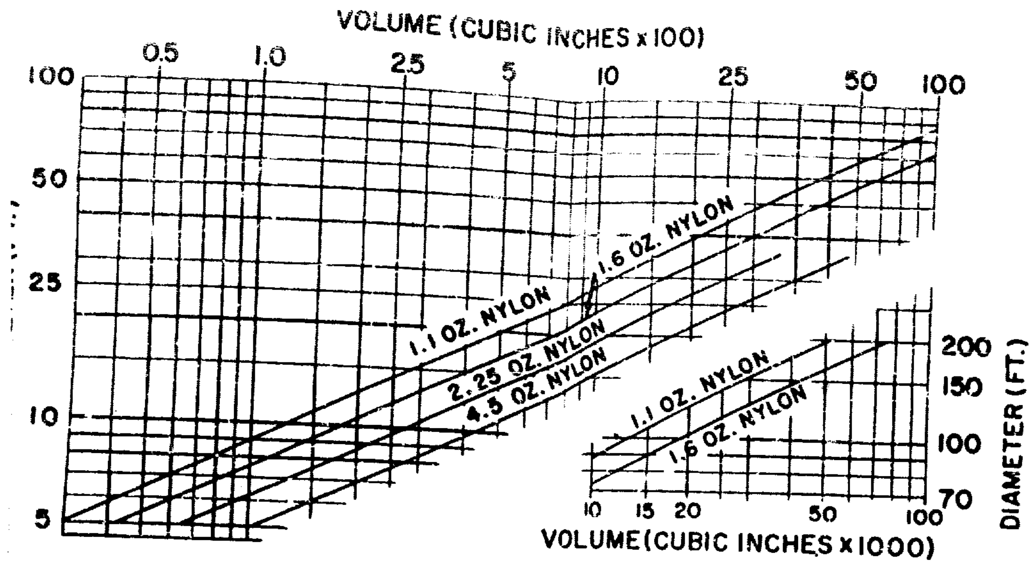
1.2.1.1 Canopy Design. This canopy is constructed as a flat circular plate with a center orifice (vent), and consists of a number of gores stitched together laterally, the joints forming the main radial seams.

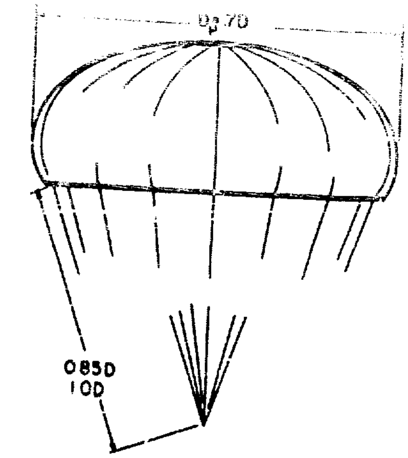
1.2.1.2 Drag Coefficient of the Canopy. The drag coefficient c_{D_0} of this type canopy ranges from 0.65 to 0.90, depending upon size and rate of descent. For preliminary calculations, an average c_{D_0} of 0.75 is generally used.

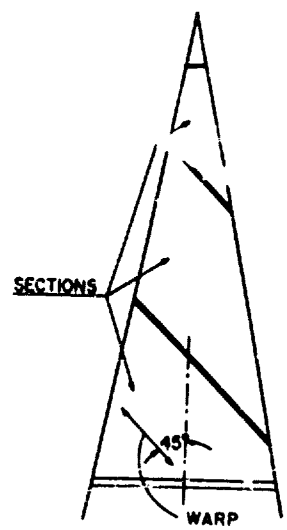
1.2.1.3 Stability of the Canopy. For small canopies (below 32-foot diameter), oscillations of

Canopy Type and Diameter	Suspende
C-9 — 28 ft.	200
G-12 — 64 ft.	2200
G-11A — 100 ft.	3500
(with 2 sec. reefing)	4500

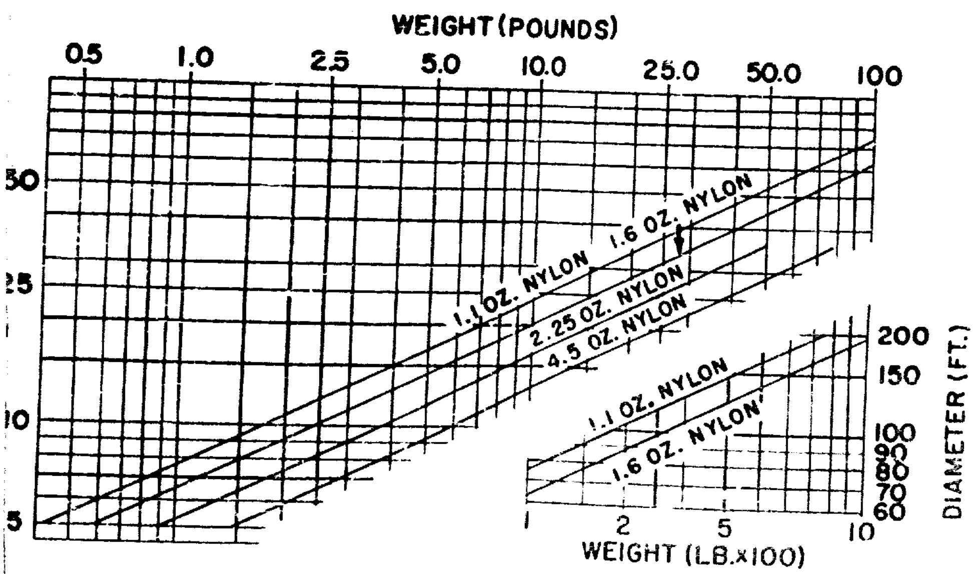


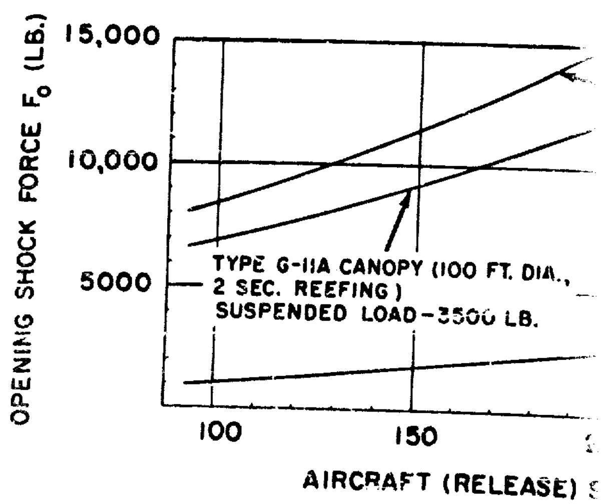


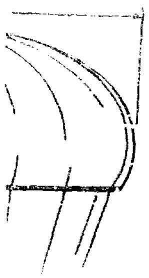




TYPICAL GORE







1.2 SOLID TEXTILE PARACHUTE CANOPIES.

1.2.1 FLAT CIRCULAR CANOPY.

1.2.1.1 Canopy Design. This canopy is constructed as a flat circular plate with a center orifice (vent), and consists of a number of gores stitched together laterally, the joints forming the main radial seams.

1.2.1.2 Drag Coefficient of the Canopy. The drag coefficient C_{D_0} of this type canopy ranges from 0.65 to 0.90, depending upon size and rate of descent. For preliminary calculations, an average C_{D_0} of 0.75 is generally used.

1.2.1.3 Stability of the Canopy. For small canopies (below 32-foot diameter), oscillations of approximately ±30 degrees are common. On larger canopies, the average angle of oscillation generally decreases.

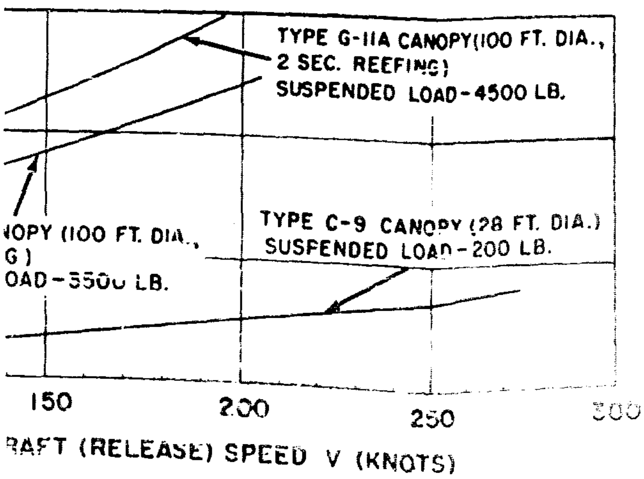
1.2.1.4 Opening Shock. For infinite mass conditions, the opening shock factor approaches 2.0.

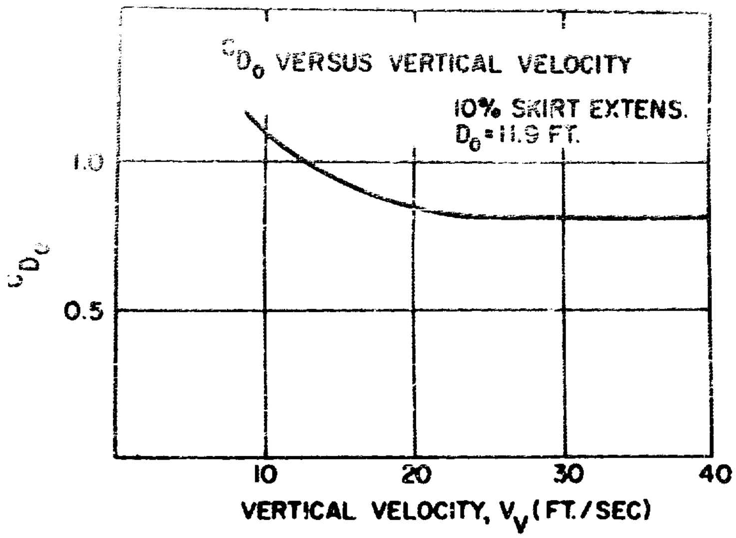
1.2.1.5 Application. Flat circular type canopies are in wide use for personnel and cargo applications.

1.2.1.6 Opening Reliability and Speed Limitations. This canopy type is very reliable. Speed limitations for this type canopy are generally low because of its rapid opening and excessive opening shock. Deployment speed limitations (safe) for several specific canopy and load configurations are as follows:

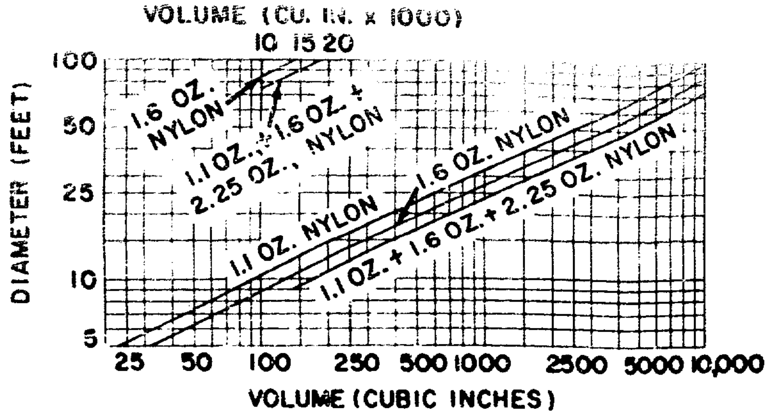
Canopy Type and Diameter	Suspended Load	Canopy Material Lines (Nylon)	Aircraft Release Velocity
C-9 – 28 ft.	200 lb.	1.1 oz. – 500 lb.	275 knots
G-12 – 64 ft.	2200 lb.	2.25 oz. – 1000 lb.	175 knots
G-11A – 100 ft.	3500 lb.	1.6 oz. – 550 lb.	205 knots
(with 2 sec. reefing)	4500 lb.	1.6 oz. – 550 lb.	195 knots

1.2.1.7 Remarks. This canopy type is relatively easy to manufacture. Its oscillation and relatively low speed characteristics make it unsuitable for certain types of application.

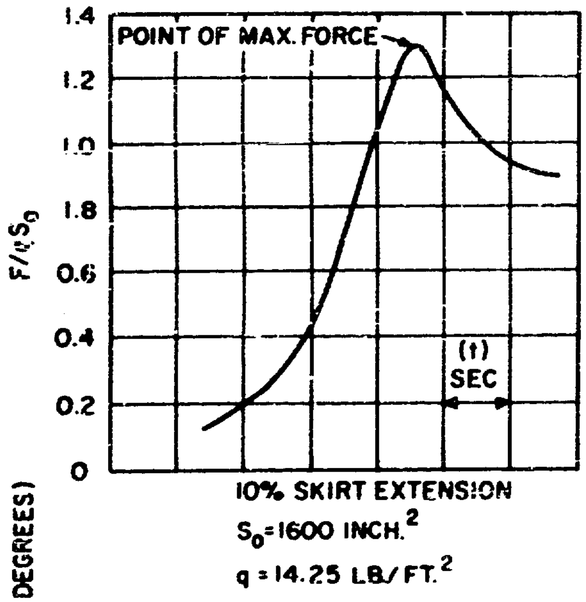




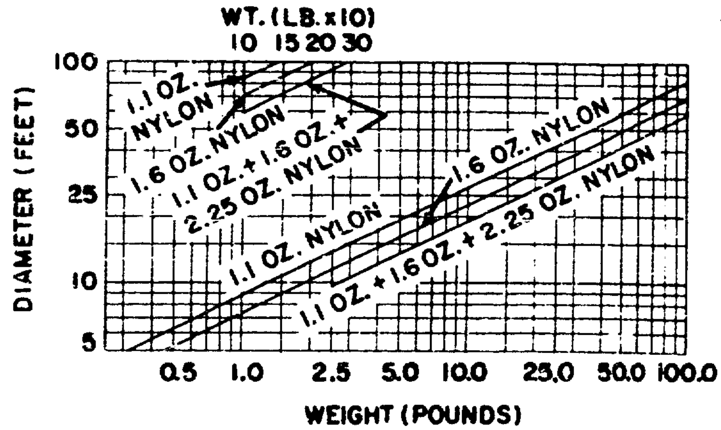
C_{D_0} VERSUS VERTICAL VELOCITY
10% SKIRT EXTENS.
D_0 = 11.9 FT.
C_{D_0}
1.0
0.5
10
20
30
40
VERTICAL VELOCITY, V_V (FT./SEC)



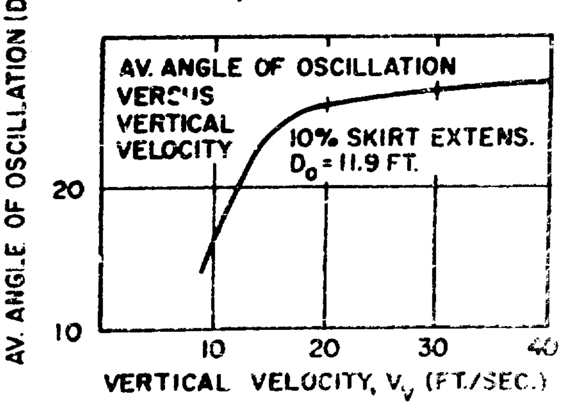
VOLUME (CU. IN. x 1000)
10 15 20
1.6 OZ. NYLON
1.1 OZ. + 1.6 OZ. + 2.25 OZ., NYLON
1.1 OZ. NYLON
1.6 OZ. NYLON
1.1 OZ. + 1.6 OZ. + 2.25 OZ. NYLON
DIAMETER (FEET)
100
50
25
10
5
25
50
100
250
500
1000
2500
5000
10,000
VOLUME (CUBIC INCHES)



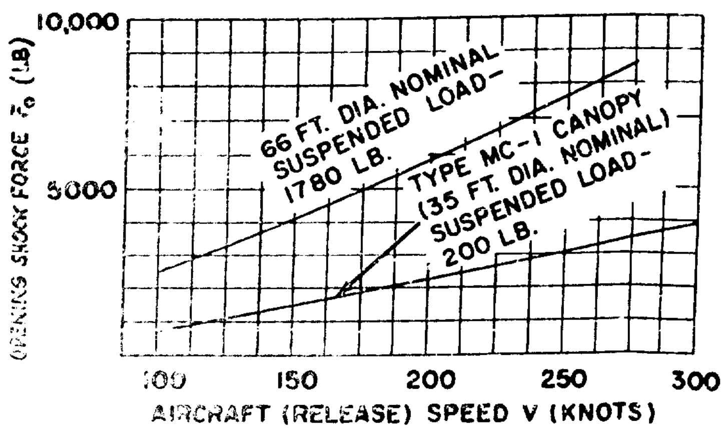
POINT OF MAX. FORCE
(t) SEC
F/qS_0
1.4
1.2
1.0
1.8
0.6
0.4
0.2
0
10% SKIRT EXTENSION
S_0 = 1600 INCH.^{2}
q = 14.25 LB./FT.^{2}



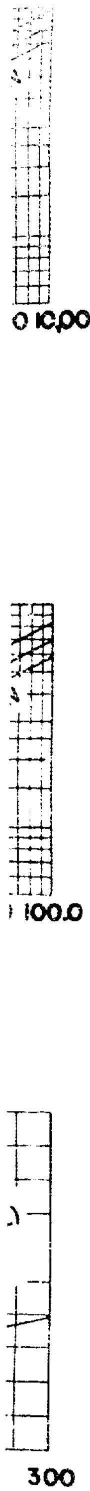
WT. (LB. x 10)
10 15 20 30
1.1 OZ. NYLON
1.6 OZ. NYLON
1.1 OZ. + 1.6 OZ. + 2.25 OZ. NYLON
1.1 OZ. NYLON
1.6 OZ. NYLON
1.1 OZ. + 1.6 OZ. + 2.25 OZ. NYLON
DIAMETER (FEET)
100
50
25
10
5
0.5
1.0
2.5
5.0
10.0
25.0
50.0
100.0
WEIGHT (POUNDS)

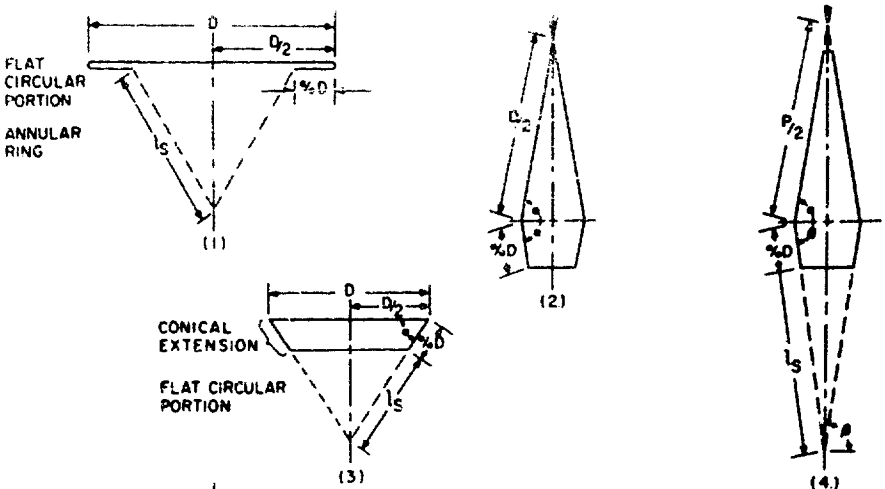


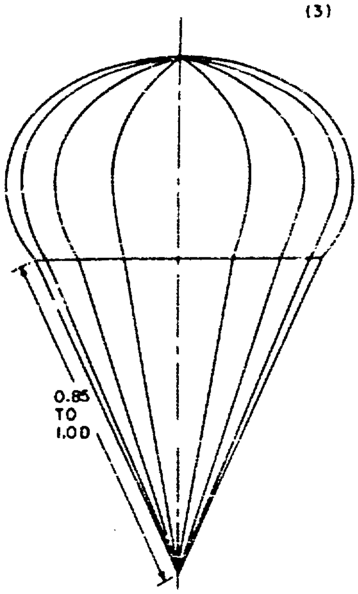
AV. ANGLE OF OSCILLATION VERSUS VERTICAL VELOCITY
10% SKIRT EXTENS.
D_0 = 11.9 FT.
AV. ANGLE OF OSCILLATION (DEGREES)
20
10
10
20
30
40
VERTICAL VELOCITY, V_V (FT./SEC.)



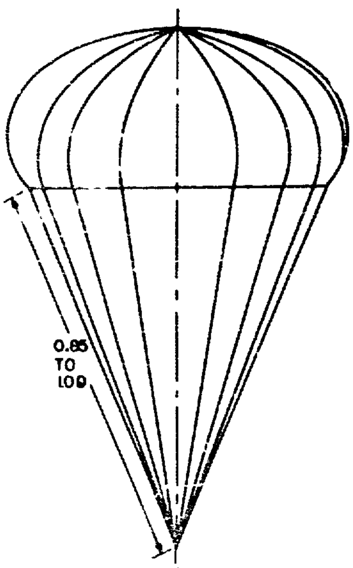
66 FT. DIA. NOMINAL SUSPENDED LOAD- 1780 LB.
TYPE MC-1 CANOPY (35 FT. DIA. NOMINAL) SUSPENDED LOAD- 200 LB.
OPENING SHOCK FORCE F_0 (LB)
10,000
5000
100
150
200
250
300
AIRCRAFT (RELEASE) SPEED V (KNOTS)







Ⓠ
FLIGHT PROFILE
FULL EXTENDED SKIRT



Ⓟ
FLIGHT PROFILE
10% EXTENDED SKIRT

1.2.2 EXTENDED SKIRT PARACH
CANOPY.

1.2.2.1 Canopy Design (Flat Ext Canopy). This design is charact flat circular center, to which is annular ring having an outer diam the diameter of the central portio designated as a percent of this shown in (1). The shape of the gore (2). The nomenclature for this ty includes the size (nominal diame the percent of the extension, in ad full name. For example: 52-foot ameter 10 percent flat extended ski canopy.

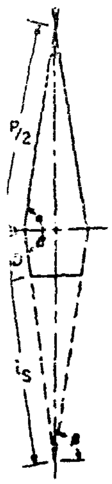
1.2.2.2 Canopy Design (Full Exte Canopy). This design is characteris circular center, to which is added ring in the form of an inverted tru having a top diameter equal to the the flat circular center portion, as s The cone angle is such that the cone the suspension lines is a continuatio verted truncated cone extension. T the gore is shown in (4). In this de β is n t equal to angle a, and mus mined i order to meet the requirem cone of the suspension lines be a co the co e of the extension. The no for this type canopy includes the si diameter D_0) and the percent of the addition to the full name. For exam foot nominal diameter 14.3 percent fu skirt parachute canopy.

1.2.2.3 Drag Coefficient of the Ca Extended Skirt). The drag coeffi averages 0.70; however, it will var of descent, size, and length of exten preliminary calculations, a C_{D_0} generally used.

Canopy Type and Diameter	S
MC-1 – 35 ft. 10% extended (nominal)	
MC-1 – 66 ft. 14.3% extended (nominal)	

1.2.2 EXTENDED SKIRT PARACHUTE CANOPY.

1.2.2.1 Canopy Design (Flat Extended Skirt Canopy). This design is characterized by a flat circular center, to which is added a flat annular ring having an outer diameter equal to the diameter of the central portion and a width designated as a percent of this diameter as shown in (1). The shape of the gore is shown in (2). The nomenclature for this type of canopy includes the size (nominal diameter D_O) and the percent of the extension, in addition to the full name. For example: 52-foot nominal diameter 10 percent flat extended skirt parachute canopy.


(4)

1.2.2.2 Canopy Design (Full Extended Skirt Canopy). This design is characterized by a flat circular center, to which is added an annular ring in the form of an inverted truncated cone having a top diameter equal to the diameter of the flat circular center portion, as shown in (3). The cone angle is such that the cone formed by the suspension lines is a continuation of the inverted truncated cone extension. The shape of the gore is shown in (4). In this design, angle β is not equal to angle α, and must be determined in order to meet the requirement that the cone of the suspension lines be a continuation of the cone of the extension. The nomenclature for this type canopy includes the size (nominal diameter D_O) and the percent of the extension in addition to the full name. For example: 67.3-foot nominal diameter 14.3 percent full extended skirt parachute canopy.

1.2.2.3 Drag Coefficient of the Canopy (Flat Extended Skirt). The drag coefficient c_{D_O} averages 0.70; however, it will vary with rate of descent, size, and length of extension. For preliminary calculations, a c_{D_O} of 0.70 is generally used.

1.2.2.4 Drag Coefficient of the Canopy (Full Extended Skirt). The drag coefficient c_{D_O} ranges between 0.70 and 0.85, depending on rate of descent and size. For preliminary calculations, a c_{D_O} of 0.70 is generally used.

1.2.2.5 Stability of the Canopy (Flat Extended Skirt). Oscillation of the flat extended skirt canopy generally ranges between ±10 and ±20 degrees, depending on design, size, and rate of descent.

1.2.2.6 Stability of the Canopy (Full Extended Skirt). Average oscillation angles for the full extended skirt canopy are slightly less than those for the flat extended skirt canopy, depending on the design.

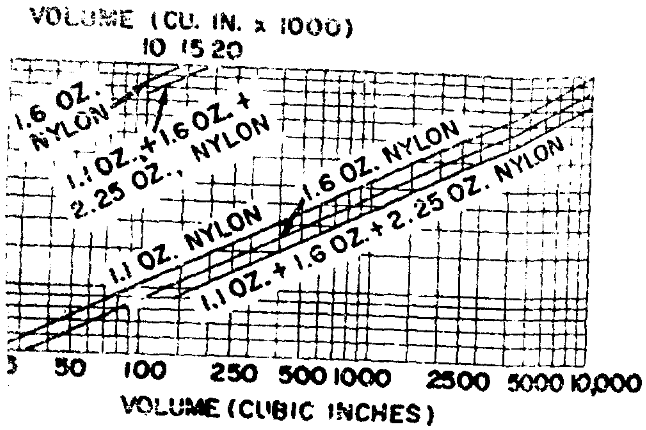
1.2.2.7 Opening Shock. For infinite mass conditions, the opening shock factor is approximately 1.8.

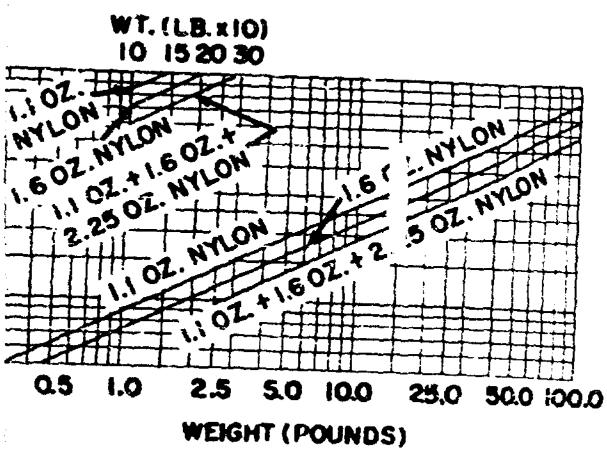
1.2.2.8 Application. At present, the full extended skirt parachute canopy is used only for cargo applications and for final stage recovery applications of guided missiles and drones. The flat extended skirt parachute canopy is being used for both personnel and cargo applications.

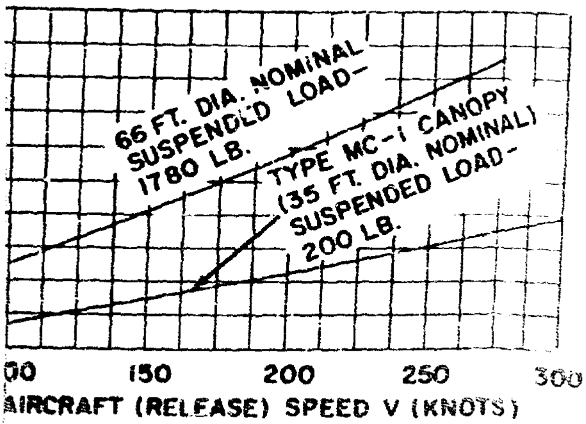
1.2.2.9 Opening Reliability and Speed Limitations. These parachute canopy types are considered to be sufficiently reliable for all cargo applications. The flat extended skirt type canopy with pocket bands is considered to be as reliable as the flat circular canopy and is used for personnel parachute applications. Because of reduced opening shock forces, these types of canopies may be used at somewhat higher deployment velocities than those of the flat circular type. Deployment speed limitations (safe) for several specific canopy and load configurations are as follows:

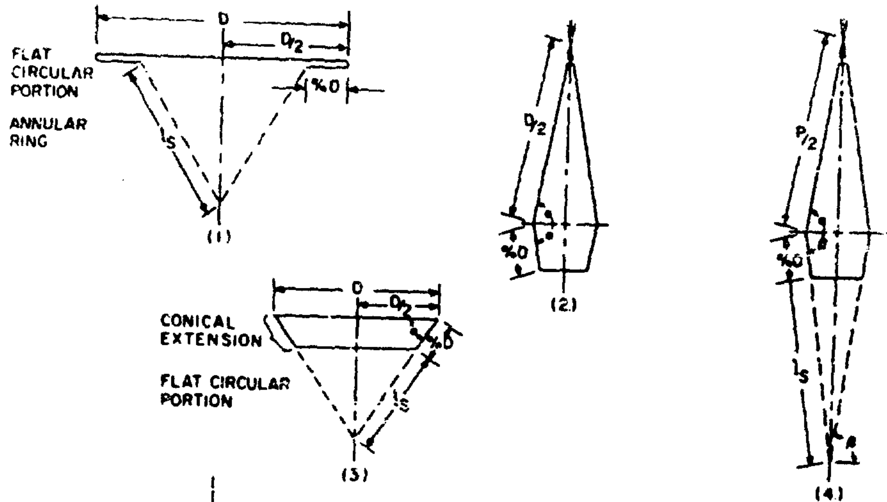
Canopy Type and Diameter	Suspended Load	Canopy Material	Lines	Aircraft Release Velocity
MC-1 – 35 ft. 10% extended (nominal)	200 lb.	1.1 oz. nylon	375 lb.	300 knots
MC-1 – 66 ft. 14.3% extended (nominal)	1800 lb.	2.25 oz. nylon	550 lb.	275 knots
		1.6 oz. nylon	550 lb.	275 knots
		1.1 oz. nylon	550 lb.	275 knots

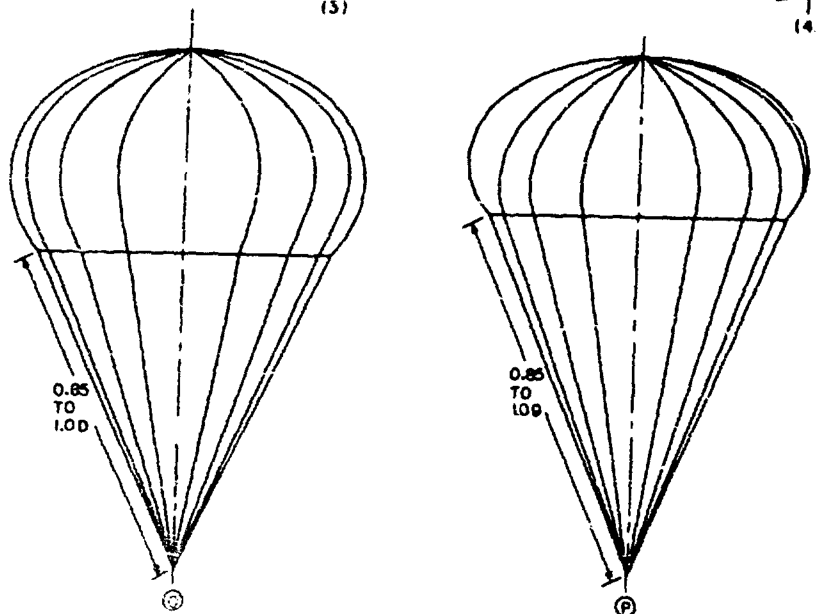
1.2.2.10 Remarks. Because of the lower drag coefficient, these parachute canopies are slightly more bulky than the flat circular type for identical rates of descent. In a similar respect, manufacturing costs are slightly higher than those for the flat circular type.





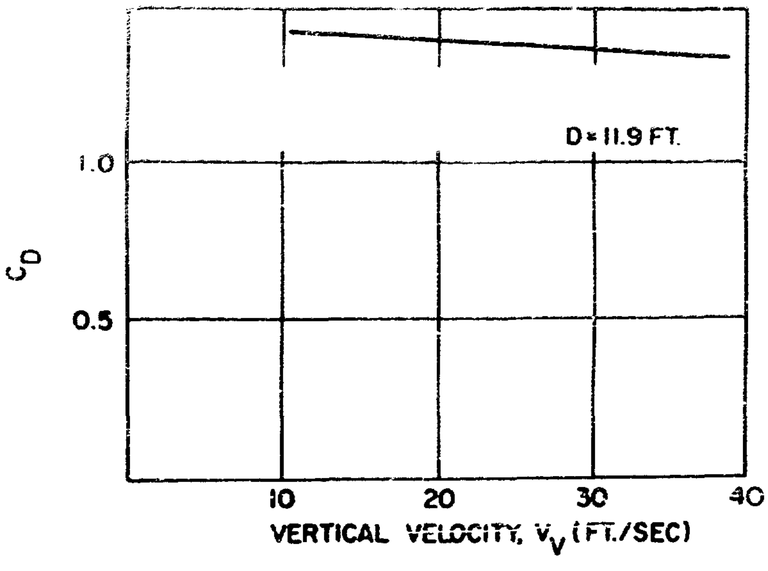




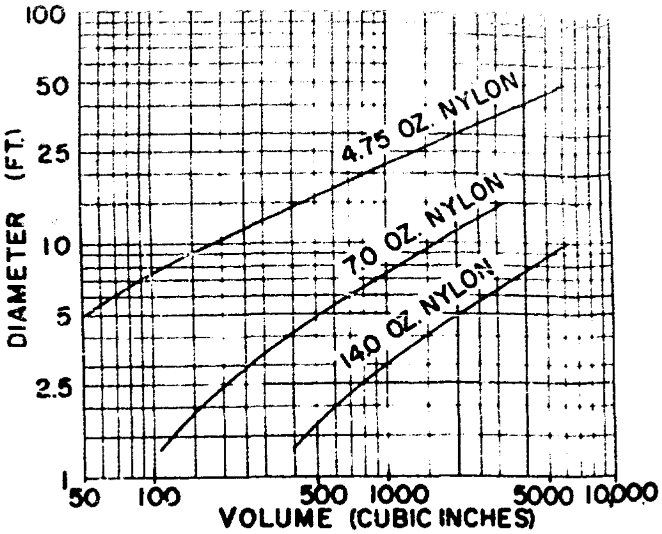


FLIGHT PROFILE FULL EXTENDED SKIRT

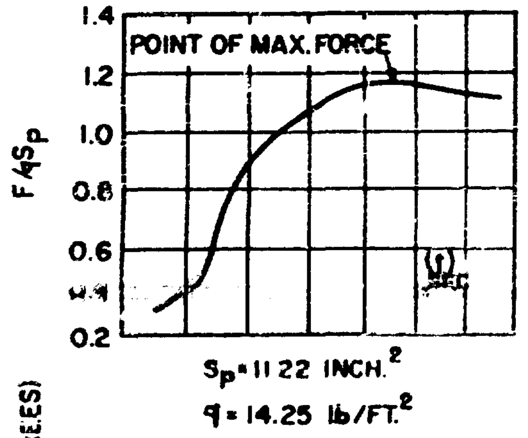
FLIGHT PROFILE 10% EXTENDED SKIRT



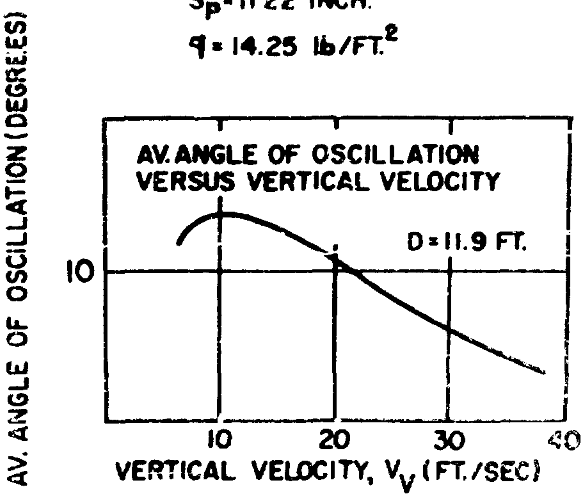
C_D
1.0
0.5
D = 11.9 FT.
10
20
30
40
VERTICAL VELOCITY, V_V (FT./SEC)



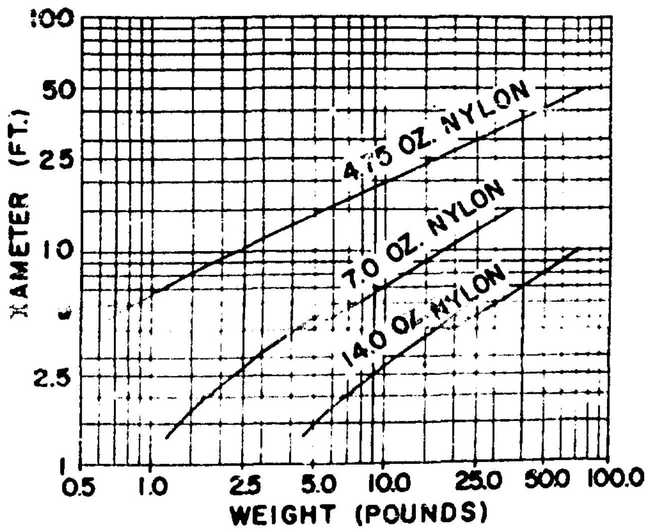
DIAMETER (FT.)
100
50
25
10
5
2.5
1
4.75 OZ. NYLON
7.0 OZ. NYLON
14.0 OZ. NYLON
50
100
500
1000
5000
10,000
VOLUME (CUBIC INCHES)



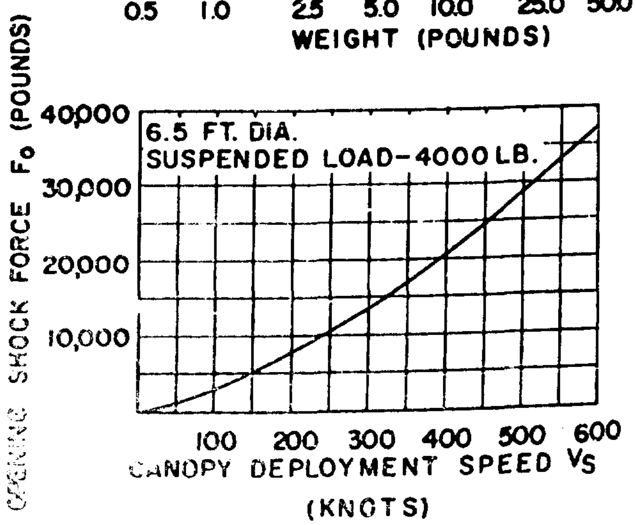
F/qS_p
1.4
1.2
1.0
0.8
0.6
0.2
POINT OF MAX. FORCE
S_p = 11.22 INCH.^{2}
q = 14.25 lb/FT.^{2}



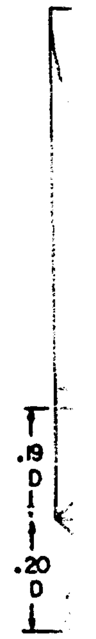
AV. ANGLE OF OSCILLATION (DEGREES)
AV. ANGLE OF OSCILLATION
VERSUS VERTICAL VELOCITY
D = 11.9 FT.
10
10
20
30
40
VERTICAL VELOCITY, V_V (FT./SEC)



DIAMETER (FT.)
100
50
25
10
2.5
1
4.75 OZ. NYLON
7.0 OZ. NYLON
14.0 OZ. NYLON
0.5
1.0
2.5
5.0
10.0
25.0
50.0
100.0
WEIGHT (POUNDS)

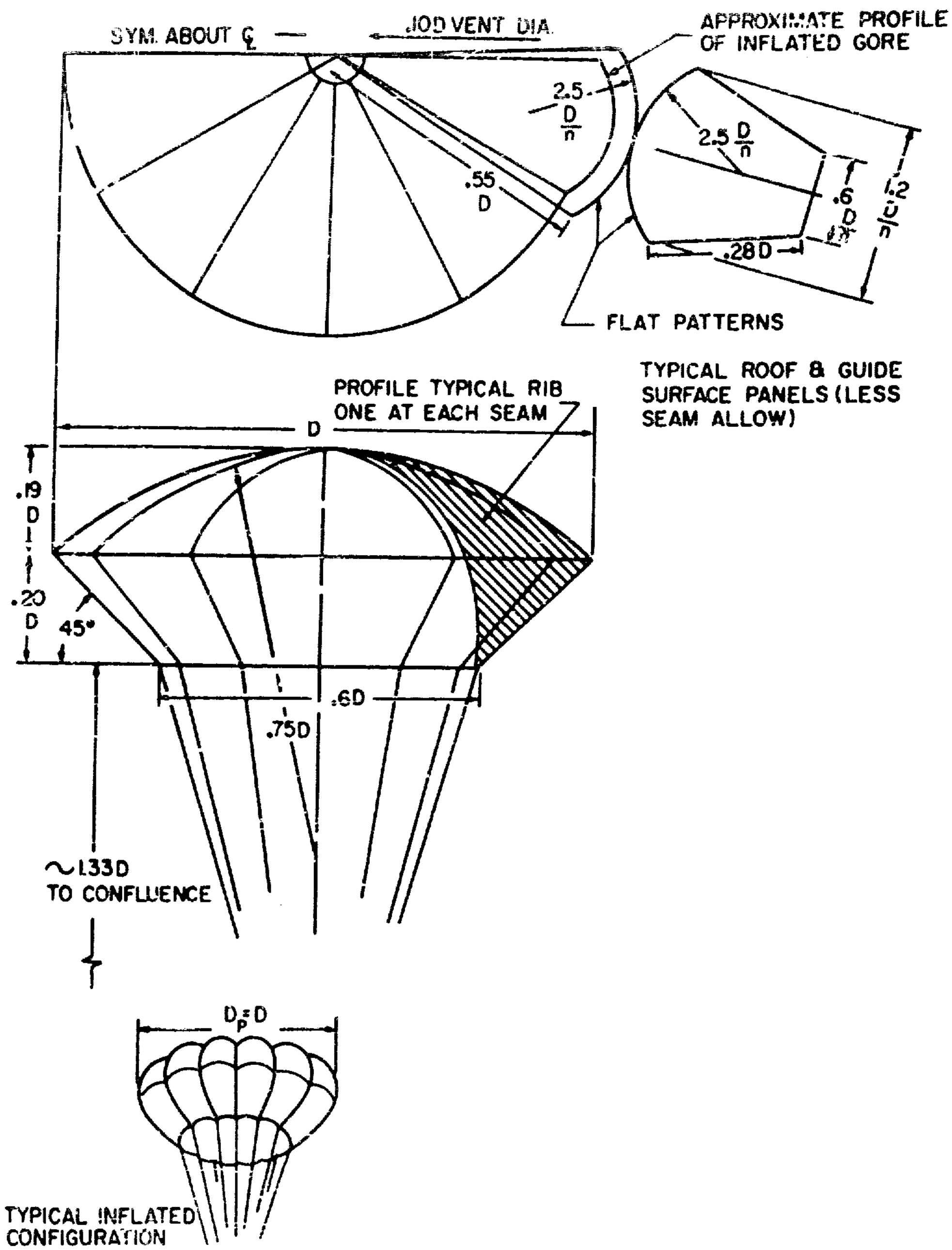


OPENING SHOCK FORCE F_o (POUNDS)
40,000
30,000
20,000
10,000
6.5 FT. DIA.
SUSPENDED LOAD-4000 LB.
100
200
300
400
500
600
CANOPY DEPLOYMENT SPEED V_S
(KNOTS)



.19 D
.20 D

TYPIC
CONF



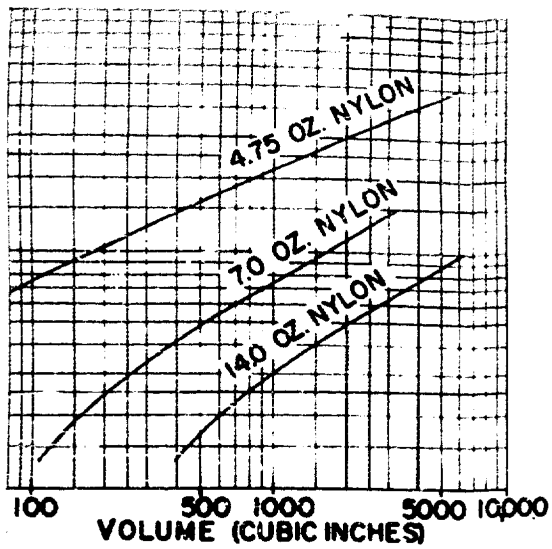
1.2.3 RIBBED GUIDE SURFACE CA

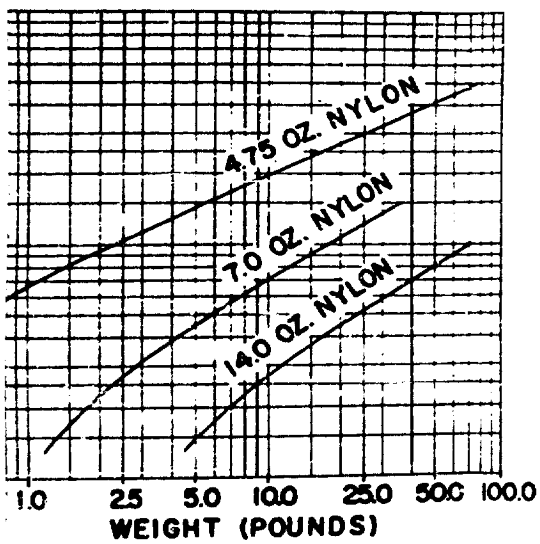
1.2.3.1 Canopy Design. This canop cate in shape. It is constructed of r guide surface panels, and internal together to form the main seams.

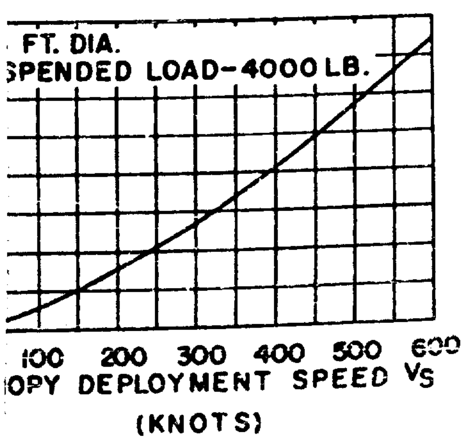
1.2.3.2 Drag Coefficient of the Ca drag coefficient c_D ranges upward For preliminary calculations, a c_D v is generally used.

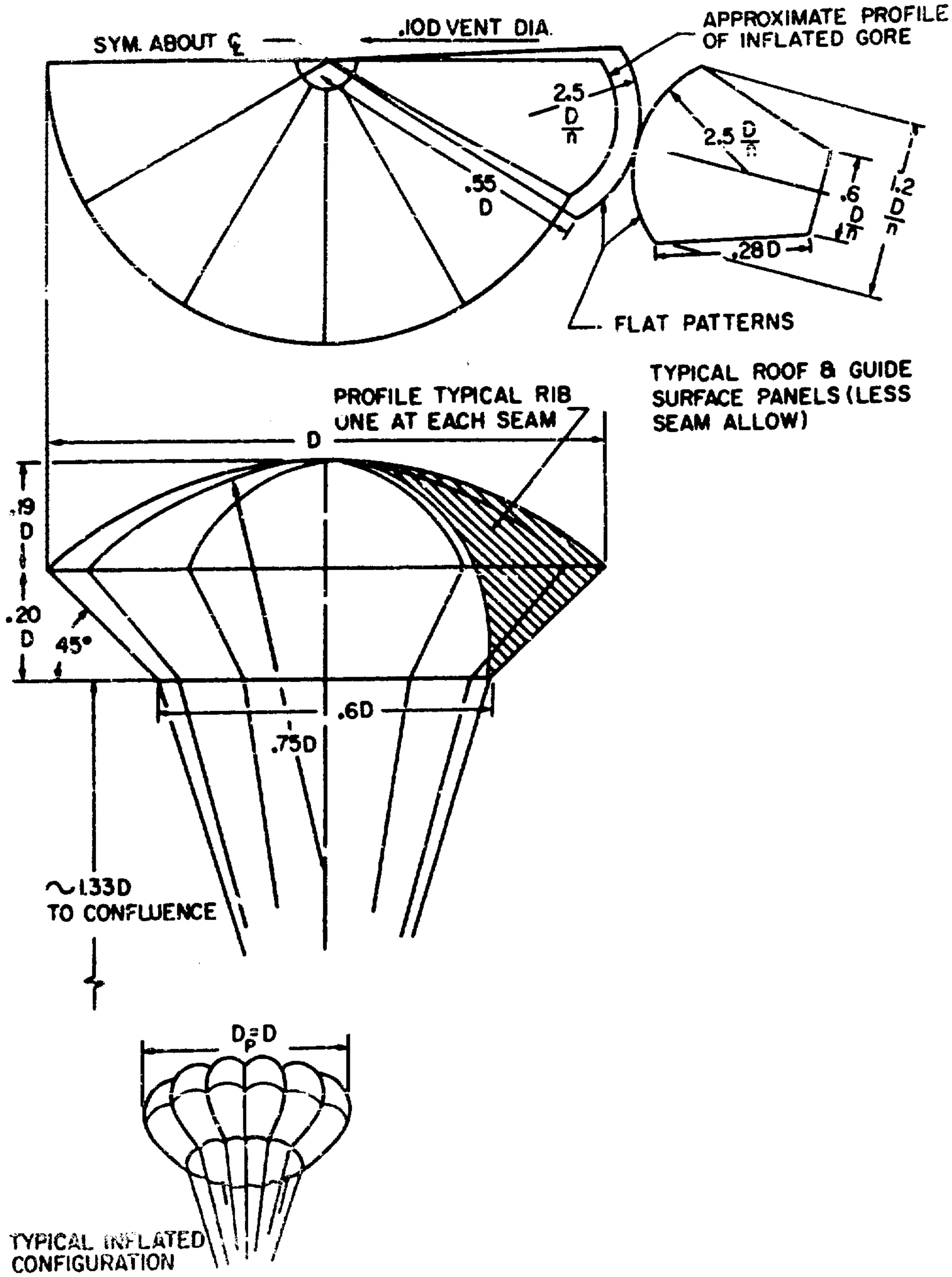
1.2.3.3 Stability of the Canopy. This canopy is extremely stable. Oscillat air averages below ±2 degrees.

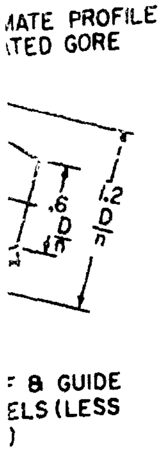
Canopy Diameter	Suspended Load
6.5 ft.	4000 lb.
6.5 ft.	4000 lb.


4.75 OZ. NYLON
7.0 OZ. NYLON
14.0 OZ. NYLON
100
500 1000
5000 10,000
VOLUME (CUBIC INCHES)


4.75 OZ. NYLON
7.0 OZ. NYLON
14.0 OZ. NYLON
1.0
2.5 5.0 10.0
25.0 50.0 100.0
WEIGHT (POUNDS)


FT. DIA.
SPENDED LOAD-4000 LB.
100 200 300 400 500 600
OPY DEPLOYMENT SPEED Vs
(KNOTS)


SYM. ABOUT ℄
.10D VENT DIA.
APPROXIMATE PROFILE
OF INFLATED GORE
2.5 D/π
.55 D
.6 D/π
1.2 D/π
.28D
FLAT PATTERNS
TYPICAL ROOF & GUIDE
SURFACE PANELS (LESS
SEAM ALLOW)
PROFILE TYPICAL RIB
LINE AT EACH SEAM
D
.19 D
.20 D
45°
.6D
.75D
~1.33D
TO CONFLUENCE
$D_P = D$
TYPICAL INFLATED
CONFIGURATION



1.2.3 RIBBED GUIDE SURFACE CANOPY.

1.2.3.1 Canopy Design. This canopy is intricate in shape. It is constructed of roof panels, guide surface panels, and internal ribs joined together to form the main seams.

1.2.3.2 Drag Coefficient of the Canopy. The drag coefficient c_D ranges upward from 0.8. For preliminary calculations, a c_D value of 0.95 is generally used.

1.2.3.3 Stability of the Canopy. This parachute canopy is extremely stable. Oscillation in free air averages below ±2 degrees.

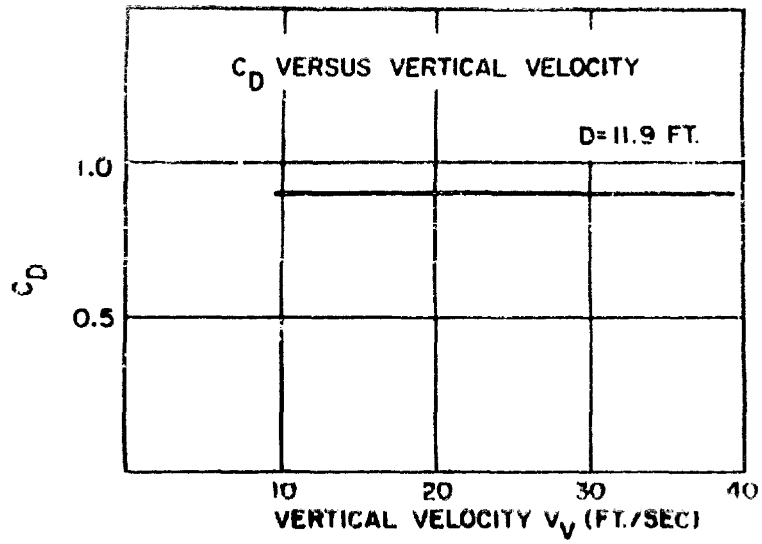
1.2.3.4 Opening Shock. For infinite mass conditions, the opening shock factor is approximately 1.1.

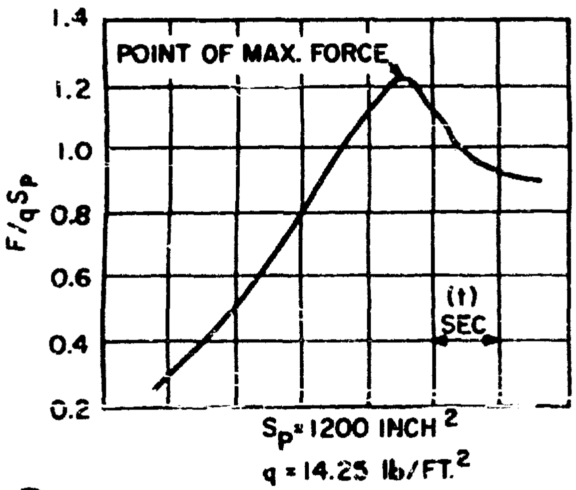
1.2.3.5 Application. This canopy type may be used for stabilization and deceleration applications, or for other applications where extreme stability, reliability, and precise reproduction of the functional sequence are required.

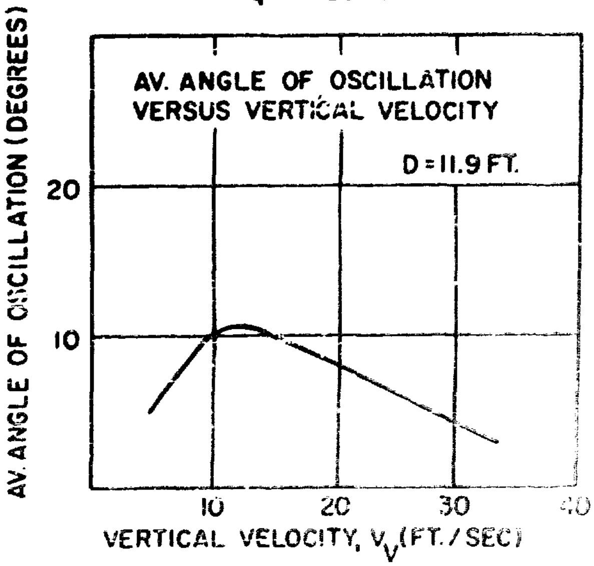
1.2.3.6 Opening Reliability and Speed Limitations. This canopy is reliable. Safe deployment speed limitations for several specific canopy configurations and nearly infinite mass conditions are as follows:

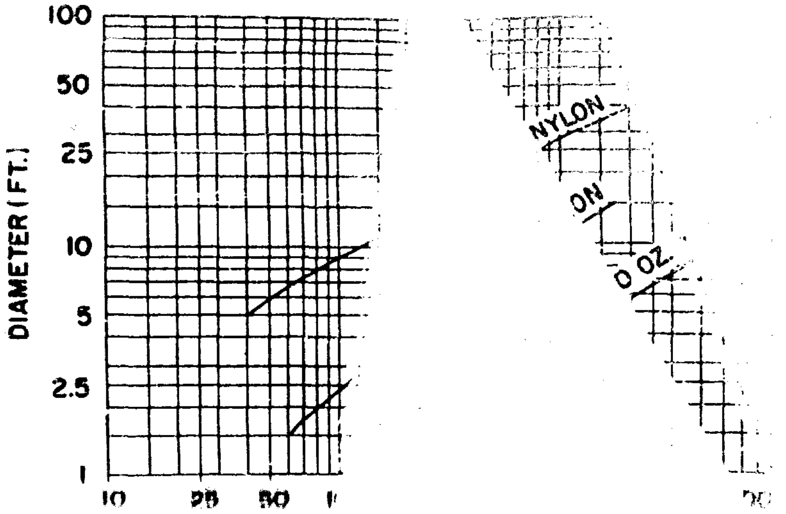
Canopy Diameter	Suspended Load	No. of Gores	Canopy Material	Lines	Deployment Speed
6.5 ft.	4000 lb.	12	7 oz. nylon	3000 lb.	350 knots
6.5 ft.	4000 lb.	16	14 oz. nylon	9000 lb.	600 knots

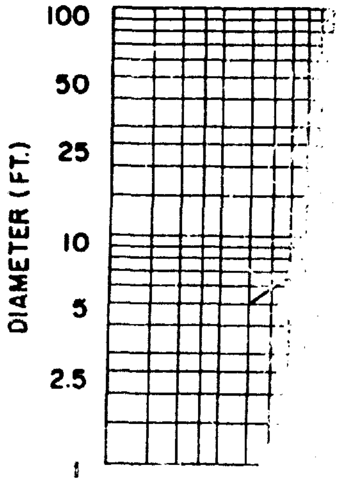
1.2.3.7 Remarks. This canopy type is somewhat difficult to manufacture, and manufacturing cost is relatively high. The ribless guide surface canopy type will generally replace the ribbed type.

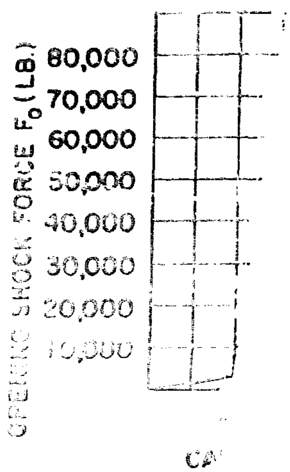

C_D VERSUS VERTICAL VELOCITY
D= 11.9 FT.
C_D
1.0
0.5
10
20
30
40
VERTICAL VELOCITY V_V (FT./SEC)

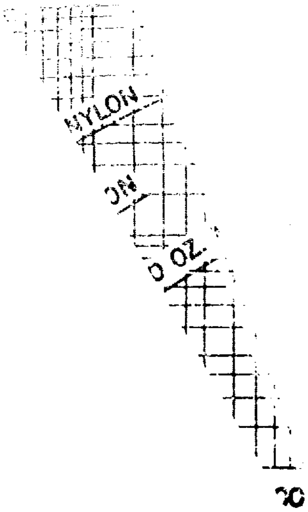

POINT OF MAX. FORCE
F/qS_p
1.4
1.2
1.0
0.8
0.6
0.4
0.2
(t)
SEC
S_p = 1200 INCH^2
q = 14.25 lb/FT.^{2}


AV. ANGLE OF OSCILLATION
VERSUS VERTICAL VELOCITY
D = 11.9 FT.
AV. ANGLE OF OSCILLATION (DEGREES)
20
10
10
20
30
40
VERTICAL VELOCITY, V_V (FT. / SEC)


100
50
25
10
5
2.5
1
DIAMETER (FT.)
10
25
50
NYLON
ON
OZ.


100
50
25
10
5
2.5
1
DIAMETER (FT.)


80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
OPENING SHOCK FORCE F_o (LB.)



1.2.4 RIBLESS GUIDE SURFACE C

.2.4.1 Canopy Design. This canop
ructed of bell-shaped roof pane
rface panels, joined together to f
ms.

3 Drag Coefficient of the C
coefficient c_D averages betw
For preliminary calculations
is generally used.

tability of the Canopy.
opy is extremely stable
mping characteristics.
below ±2 degrees.

r	Suspended Lo
	4000 lb.
	4000 lb.

1.2.4 RIBLESS GUIDE SURFACE CANOPY.

1.2.4.1 Canopy Design. This canopy type is constructed of bell-shaped roof panels and guide surface panels, joined together to form the main seams.

1.2.4.2 Drag Coefficient of the Canopy. The drag coefficient c_D averages between 0.75 and 0.85. For preliminary calculations, a c_D value of 0.80 is generally used.

1.2.4.3 Stability of the Canopy. This parachute canopy is extremely stable and has excellent damping characteristics. Oscillation in free air is below ± 2 degrees.

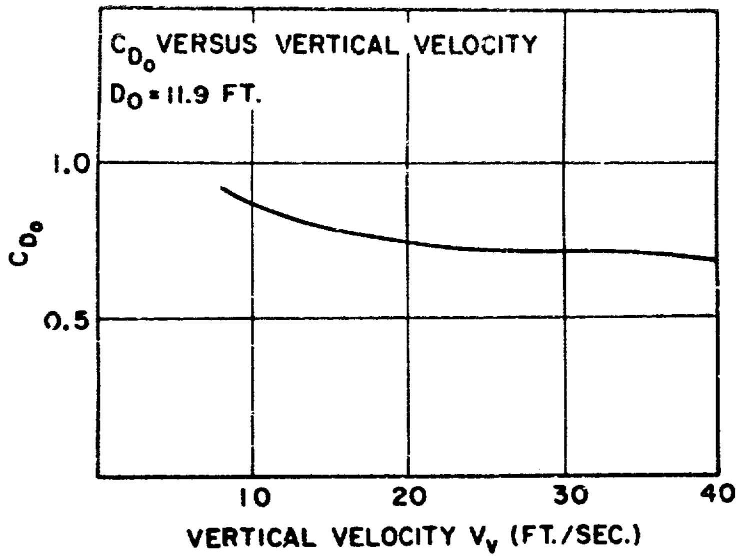
1.2.4.4 Opening Shock. For infinite mass conditions, the opening shock factor ranges between 1.1 and 1.4, depending on specific design characteristics.

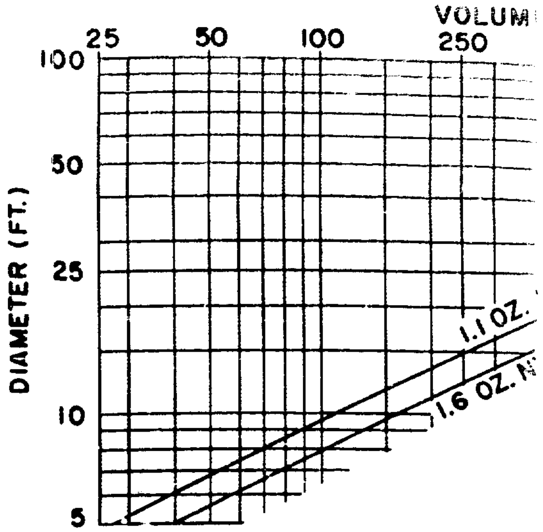
1.2.4.5 Application. This parachute canopy may be used for stabilization, deceleration, or extraction applications, and for other applications requiring extreme stability, precise functioning, and high reliability.

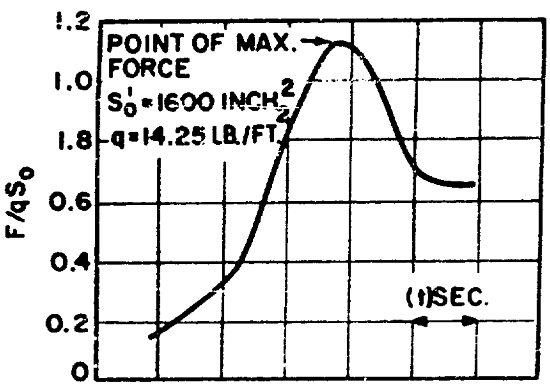
1.2.4.6 Opening Reliability and Speed Limitations. This parachute canopy is reliable. Deployment speed limitations for specific canopy configurations and nearly infinite mass conditions are as follows:

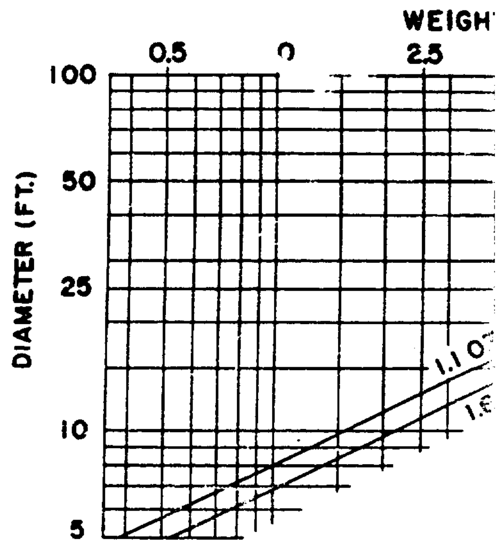
Canopy Diameter	Suspended Load	No. of Gores	Canopy Material	Lines	Deployment Speed
6.5 ft.	4000 lb.	12	7 oz. nylon	3000 lb.	350 knots
6.5 ft.	4000 lb.	16	14 oz. nylon	9000 lb.	750 knots

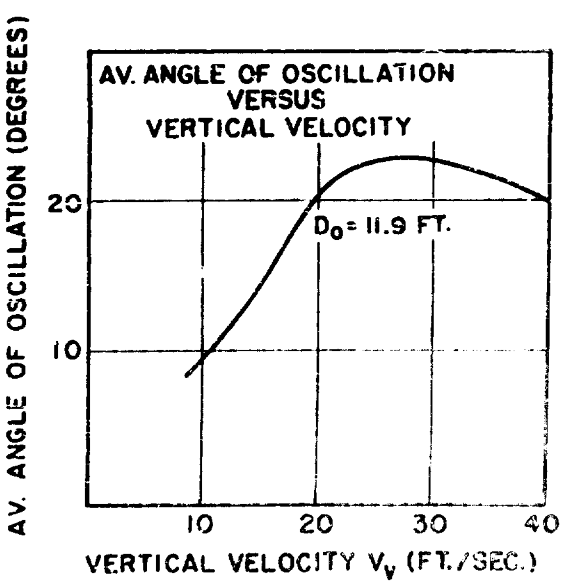
1.2.4.7 Remarks. The manufacturing cost of this parachute canopy type is somewhat less than that of the ribbed type. For most applications it can replace the ribbed type.

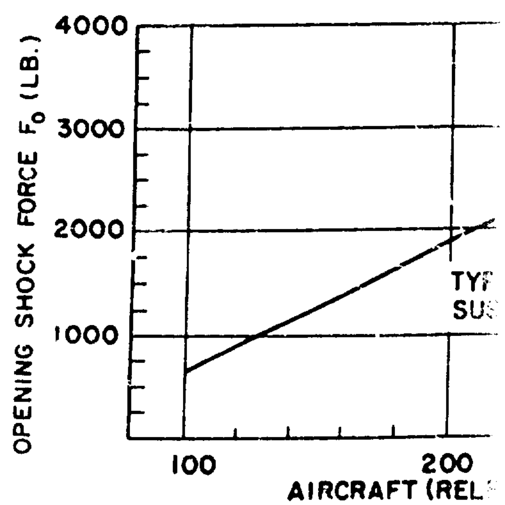

C_{D_0} VERSUS VERTICAL VELOCITY
D_O = 11.9 FT.
C_{D_0}
1.0
0.5
10
20
30
40
VERTICAL VELOCITY V_V (FT./SEC.)

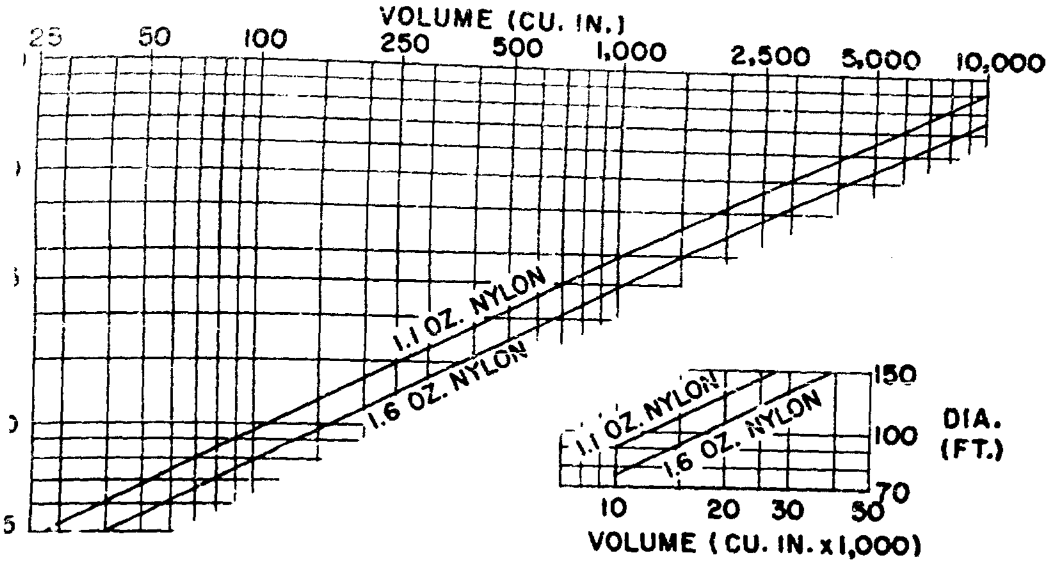

VOLUM
25
50
100
250
100
50
25
10
5
DIAMETER (FT.)
1.1 OZ.
1.6 OZ.

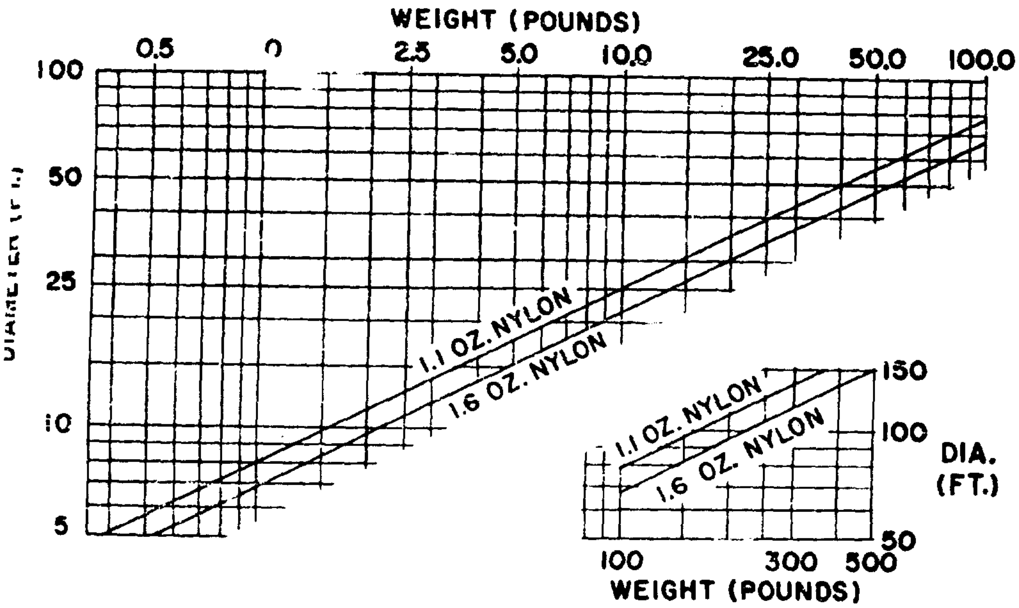

POINT OF MAX. FORCE
S_0' = 1600 INCH^2
q = 14.25 LB./FT.^{2}
F/qSo
1.2
1.0
1.8
0.6
0.4
0.2
0
(t)SEC.

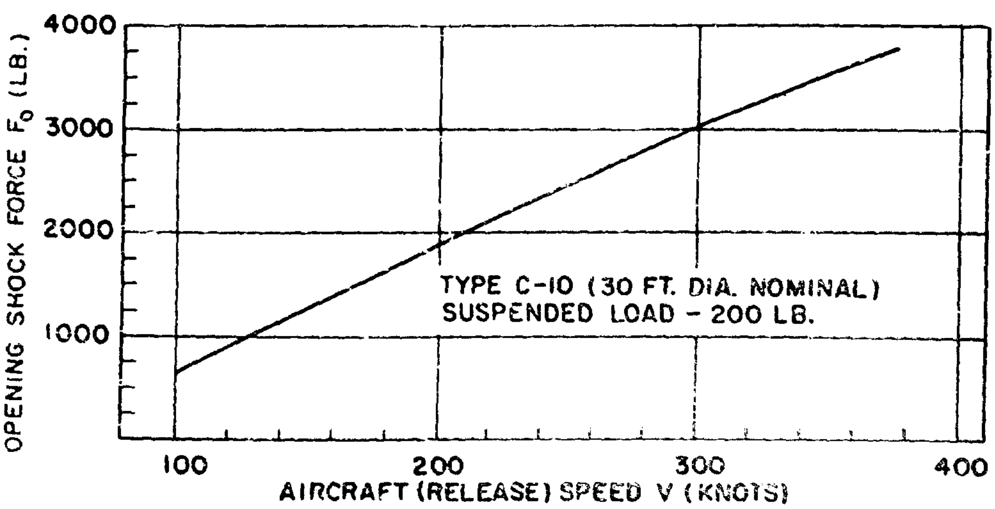

WEIGH
0.5
2.5
100
50
25
10
5
DIAMETER (FT.)


AV. ANGLE OF OSCILLATION
VERSUS
VERTICAL VELOCITY
D_O = 11.9 FT.
AV. ANGLE OF OSCILLATION (DEGREES)
20
10
10
20
30
40
VERTICAL VELOCITY V_V (FT./SEC.)


OPENING SHOCK FORCE F_o (LB.)
4000
3000
2000
1000
100
200
AIRCRAFT (REL







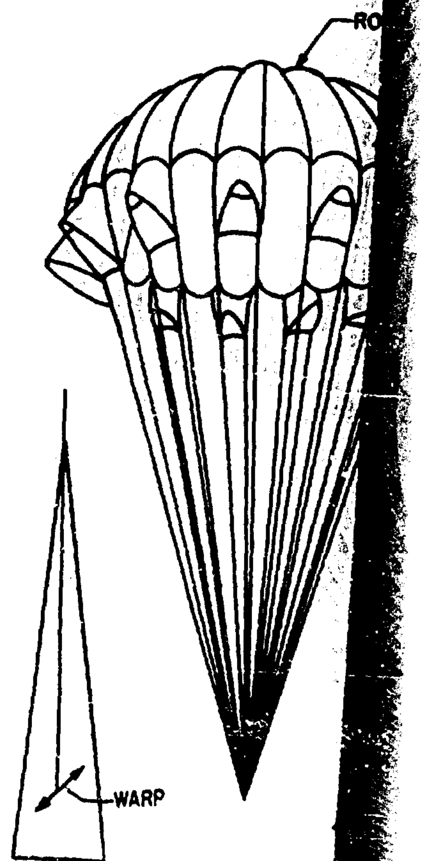
1.2.5 PERSONNEL GUIDE SUR

1.2.5.1 Canopy Design. The identical in construction to circular type canopy. Alternat extended to provide the guid guide surfaces somewhat rese in ribless guide surface canop

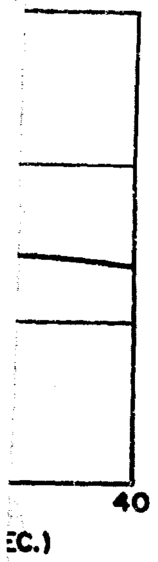
1.2.5.2 Drag Coefficient of t drag coefficient c_{D_0} of this ca slightly less than that for t flat circular type. For prel tions, a c_{D_0} value of 0.72 is g

1.2.5.3 Stability of the Canopy canopy is considered stable.

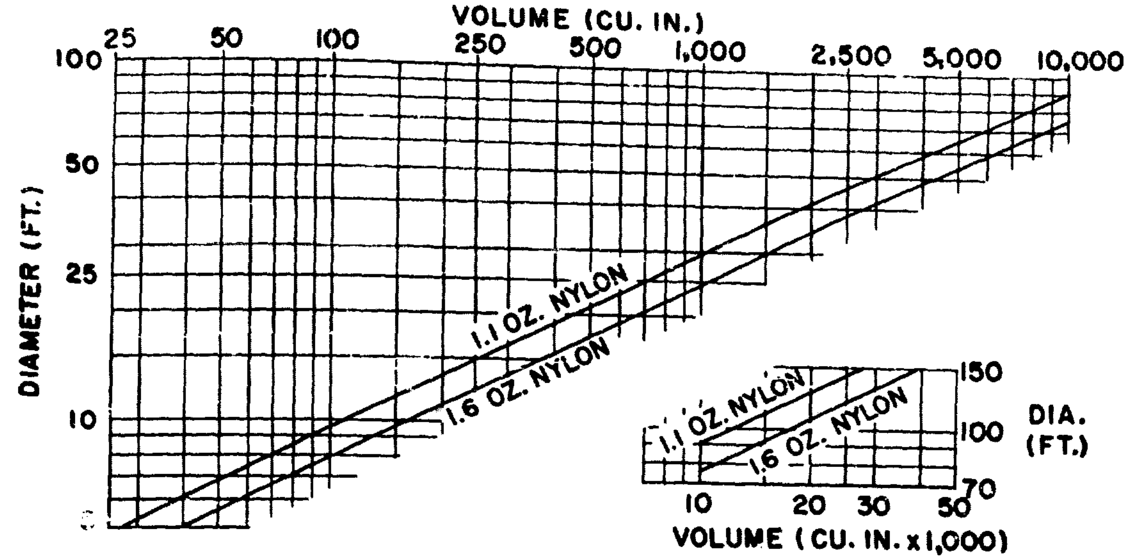
Canopy Type and Diameter	Susp
C-10 — 30 ft. (nominal)	



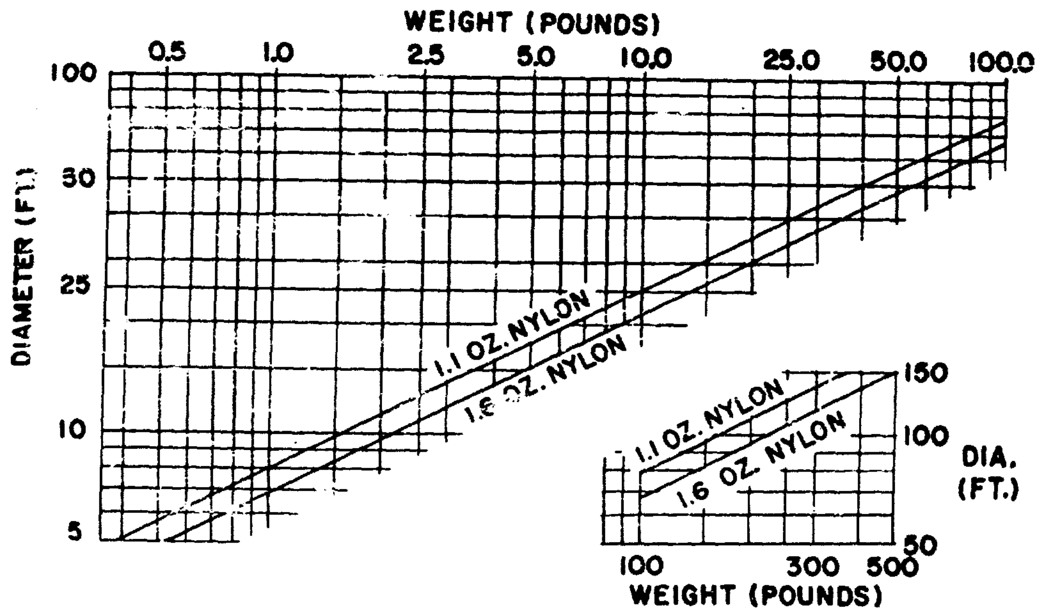
DETAIL-ROOF PANEL D



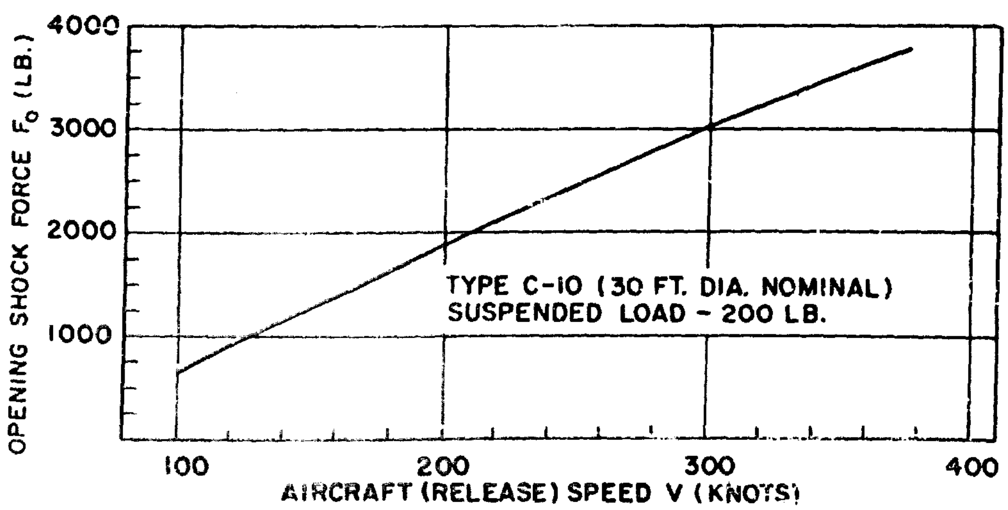
40
EC.)



VOLUME (CU. IN.)
25
50
100
250
500
1,000
2,500
5,000
10,000
100
50
25
10
DIAMETER (FT.)
1.1 OZ. NYLON
1.6 OZ. NYLON
150
100
70
DIA. (FT.)
10
20
30
50
VOLUME (CU. IN. x 1,000)



WEIGHT (POUNDS)
0.5
1.0
2.5
5.0
10.0
25.0
50.0
100.0
100
50
25
10
5
DIAMETER (FT.)
1.1 OZ. NYLON
1.6 OZ. NYLON
150
100
50
DIA. (FT.)
100
300
500
WEIGHT (POUNDS)



4000
3000
2000
1000
OPENING SHOCK FORCE F_o (LB.)
TYPE C-10 (30 FT. DIA. NOMINAL)
SUSPENDED LOAD - 200 LB.
100
200
300
400
AIRCRAFT (RELEASE) SPEED V (KNOTS)

1.2.5 PERSONNEL GUIDE SURFACE CANOPY.

1.2.5.1 Canopy Design. The roof panels are identical in construction to those of the flat circular type canopy. Alternate roof panels are extended to provide the guide surfaces. The guide surfaces somewhat resemble those found in ribless guide surface canopies.

1.2.5.2 Drag Coefficient of the Canopy. The drag coefficient c_{D_0} of this canopy type is only slightly less than that for the very efficient flat circular type. For preliminary calculations, a c_{D_0} value of 0.72 is generally used.

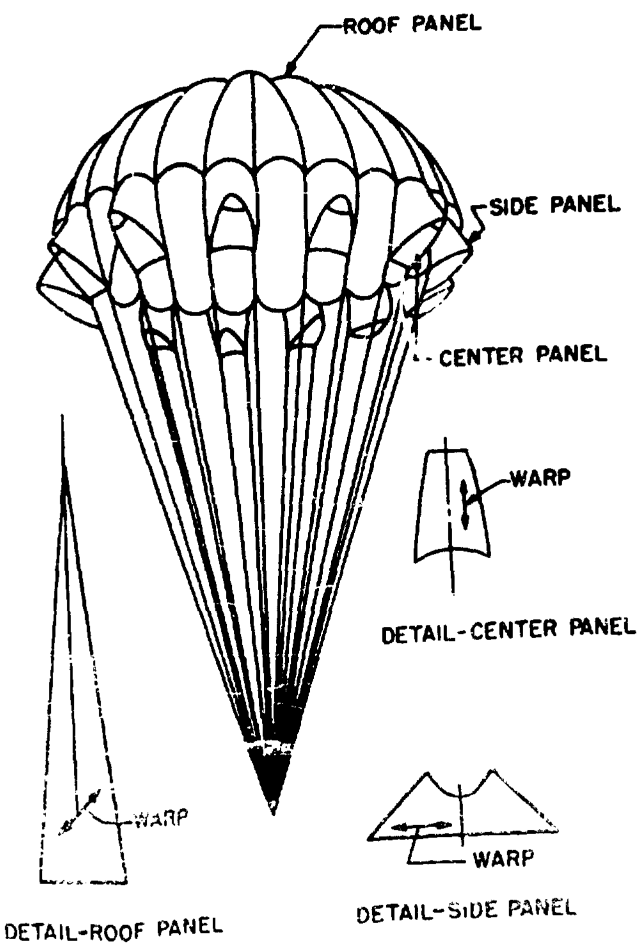
1.2.5.3 Stability of the Canopy. This parachute canopy is considered stable. Oscillations in free air are below ±10 degrees.

1.2.5.4 Opening Shock. For infinite mass conditions, the opening shock factor approaches 1.2.

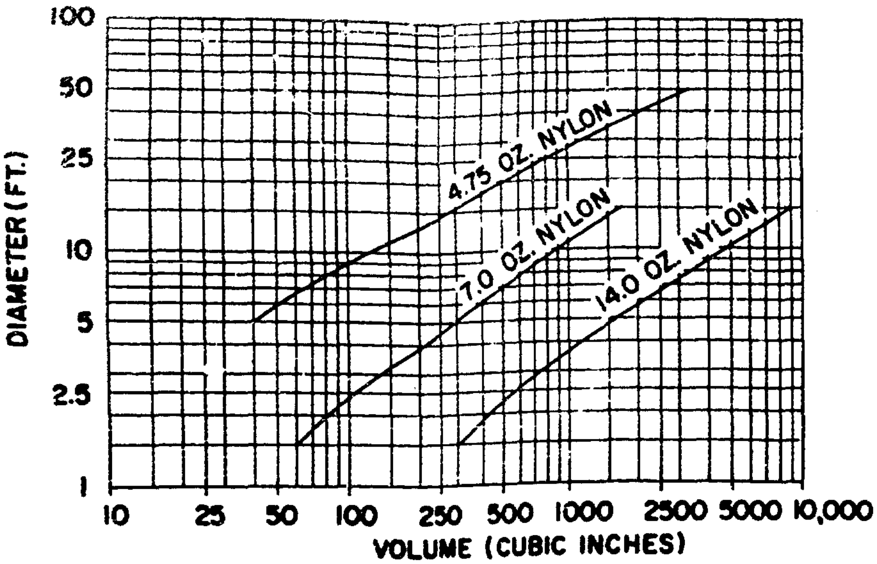
1.2.5.5 Application. The primary application is for personnel emergency use; however, some designs of this canopy type have been used for recovery applications. This canopy has all the advantages of the flat circular type canopy, plus a considerable improvement in maximum operational speed, stability, and opening shock.

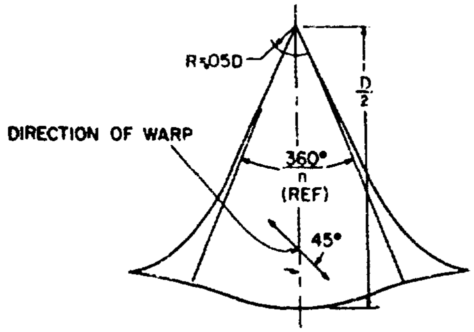
1.2.5.6 Opening Reliability and Speed Limitations. This canopy type is reliable, and can safely be used up to 375 knots bailout velocity at sea level for the following canopy and suspended load configuration:

Canopy Type and Diameter	Suspended Load	Canopy Material	Deployment Speed
C-10 – 30 ft. (nominal)	200 lb.	1.1 oz. nylon	375 knots

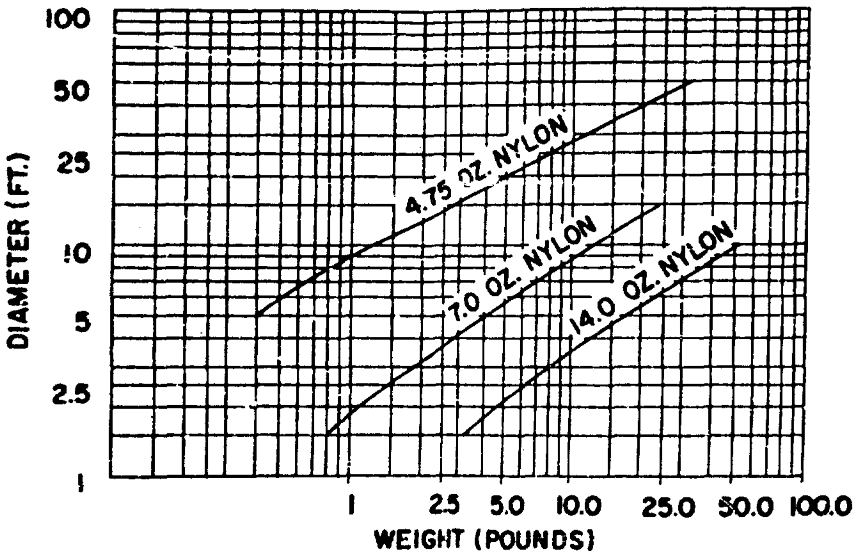


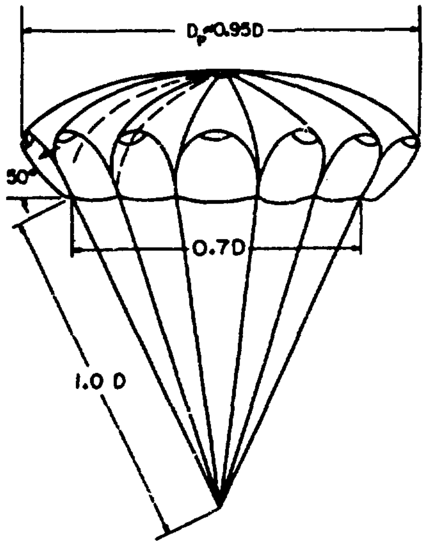
1.2.5.7 Remarks. The guide surface extensions add only slightly to the manufacturing cost. The bulk, weight, and rate of descent are approximately the same as for a comparable flat circular type canopy.

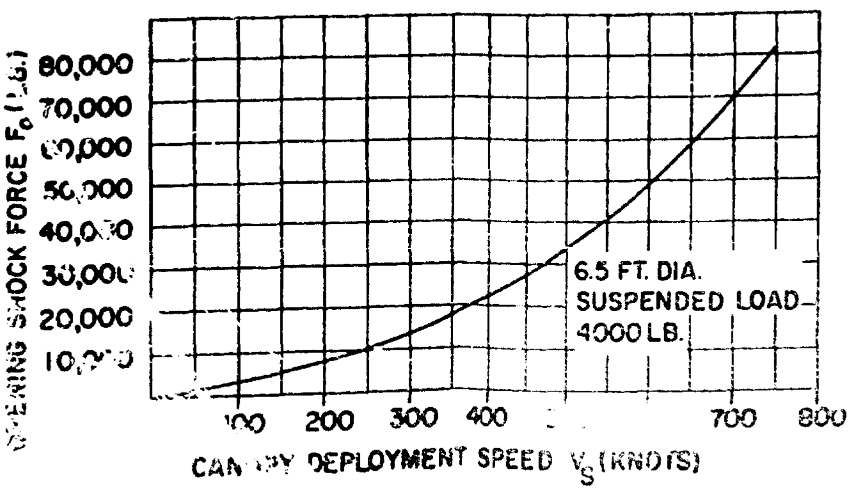


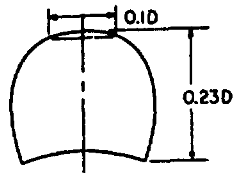


TYPICAL TOP PANEL



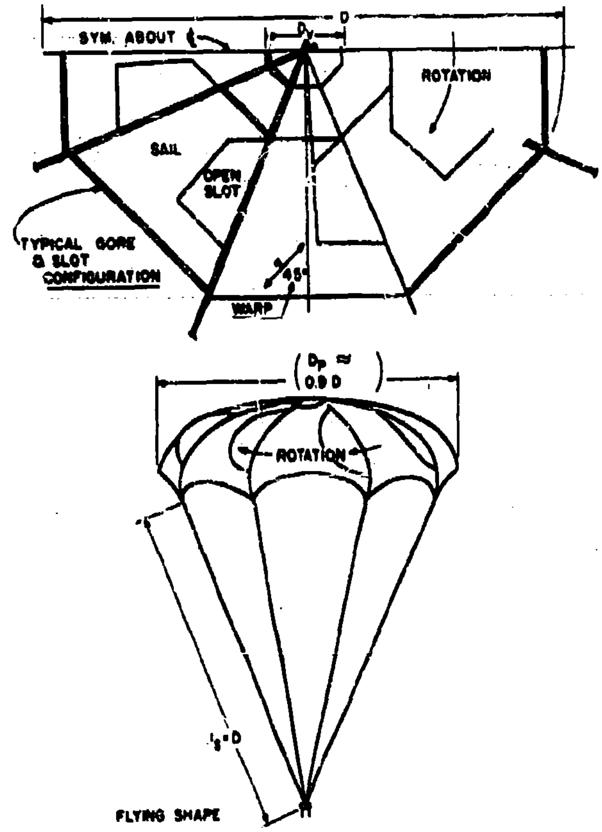






TYPICAL GUIDE SURFACE PANEL

1.2.6 ROTAFOIL CANOPY.



1.2.6.1 Canopy Design. This parachute was developed by Radioplane Company, Van Nuys, California, under contract with the United States Government. Construction of the canopy is similar to that of the flat circular type. Openings in each gore transform each roof panel into a sail during operation, which causes rapid canopy rotation. A swivel has to be used to permit this rotation relative to the suspended load, while transmitting minimum torque to the load.

1.2.6.2 Drag Coefficient of the Canopy. The drag coefficient c_{D_O} varies according to the design. On types tested it has ranged from 0.63 to 0.90. For preliminary calculations, a c_{D_O} value of 0.78 is generally used.

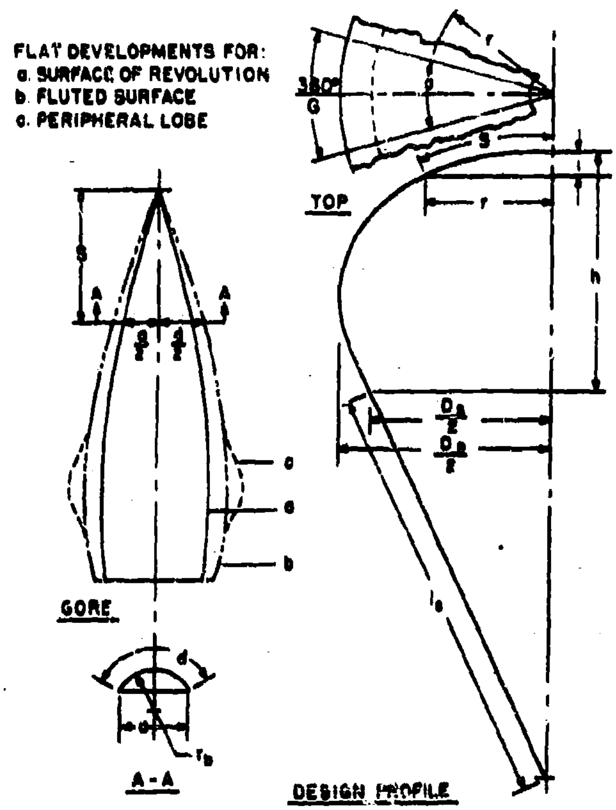
1.2.6.3 Stability of the Canopy. At present, the stability of this canopy type is very much a function of the design. Models range from stable to unstable, with the loss of certain desirable characteristics in the stable models.

1.2.6.4 Opening Shock. For infinite mass conditions, the opening shock factor is approximately 1.06.

1.2.6.5 Application. This parachute canopy may be used for deceleration applications.

1.2.6.6 Opening Reliability and Speed Limitations. Most designs are reliable. Canopies (7-foot diameter) constructed of 7-ounce nylon and 3,000-pound tensile strength suspension lines have been deployed safely at deployment speeds of 350 knots under nearly infinite mass conditions.

1.2.6.7 Remarks. This canopy type may offer possibilities of specialized development for specific purposes. The parachute canopy itself is low in bulk and weight, but because of the required swivel (and lead loading of the canopy skirt for several types), this parachute becomes bulkier and weighs more than do comparable ribbon, ring slot, or guide surface type parachutes.



1.2.7 SHAPED CANOPY.

1.2.7.1 Canopy Design. This canopy design is similar to that of the solid flat type, with the exception that the panels are shaped. Because of the many variations of shaped canopy designs, it is impractical to cite "specific performance" figures.

1.2.7.2 Drag Coefficient of the Canopy. Many shaped designs have been tested; some have achieved drag coefficients even higher than those obtained for the flat circular type.

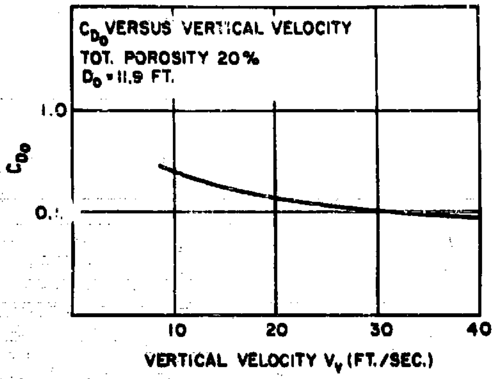
1.2.7.3 Stability of the Canopy. Stability varies with design. Some of the types tested have shown very little tendency to oscillate.

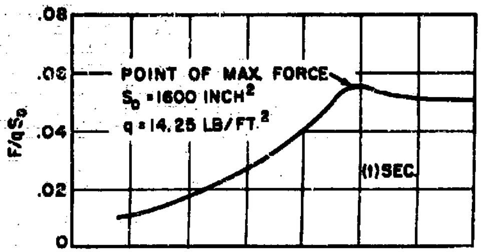
1.2.7.4 Opening Shock. For infinite mass conditions, the opening shock factor is slightly less than those for other comparable canopy designs.

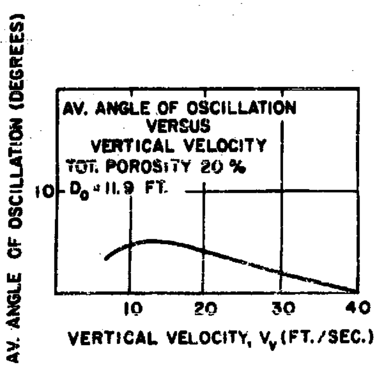
1.2.7.5 Application. These parachute canopy types may be designed for applications that require reduced opening shock and/or greater stability than is found in flat circular type canopies.

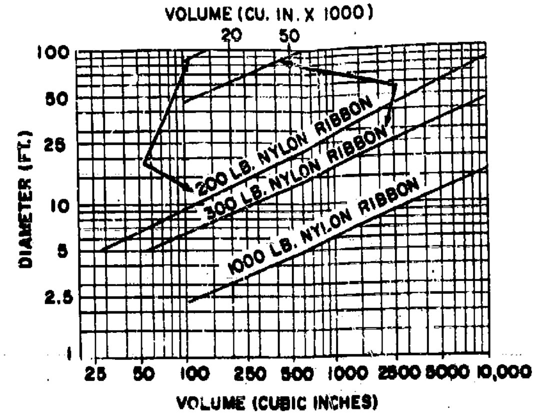
1.2.7.6 Opening Reliability. Reliability varies greatly with design. Conical canopy designs have been found reliable for several applications.

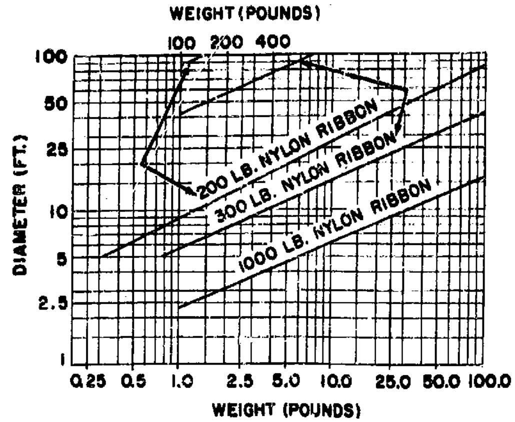
1.2.7.7 Remarks. Shaped canopies generally have slightly more bulk and weight than others used for comparable applications.

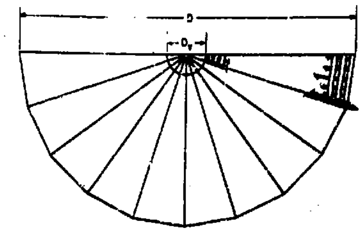


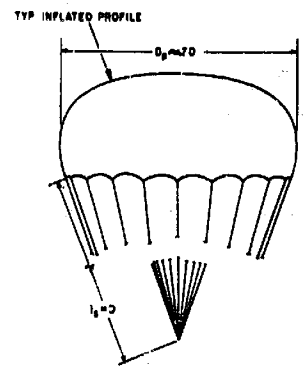


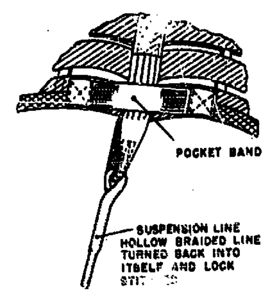


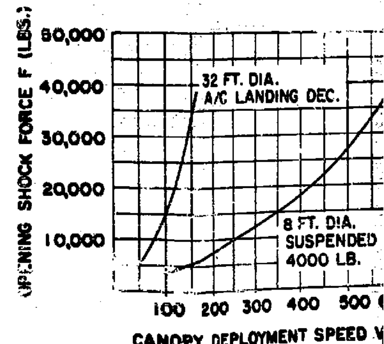












1.3 RIBBON PARACHUTE CANO

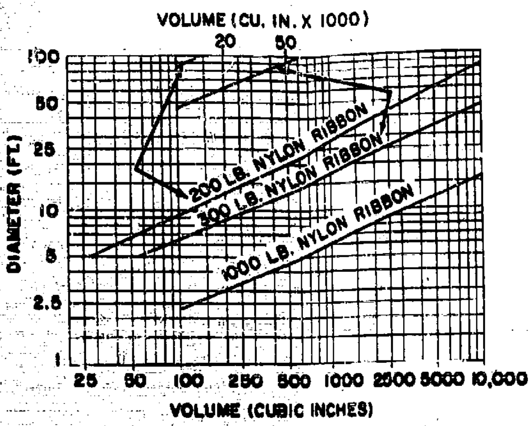
1.3.1 FIST RIBBON CANOPY.

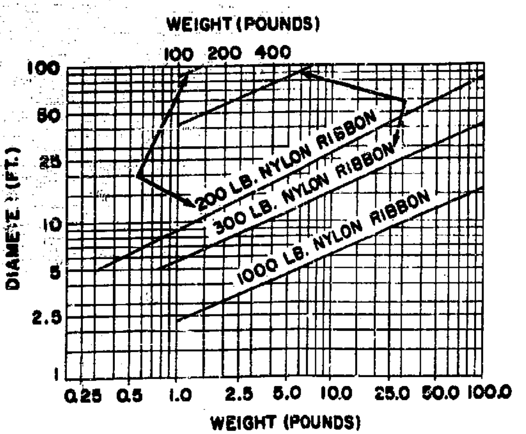
1.3.1.1 Canopy Design. This ca circular design and composed of c bons, supported by a number of and smaller semiradial supportin

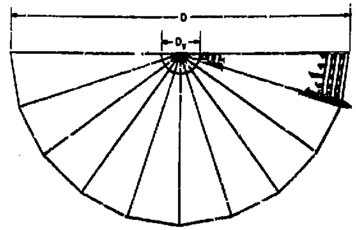
1.3.1.2 Drag Coefficient of the drag coefficient c_{D_0} ranges bet 0.55, depending on design, size, an For preliminary design purpose of 0.5 is generally used.

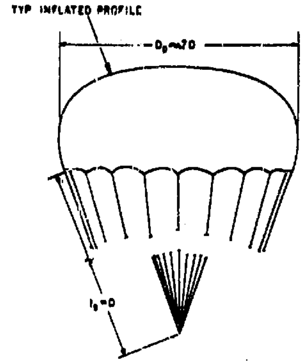
1.3.1.3 Stability of the Canopy. very stable. Oscillations in fr

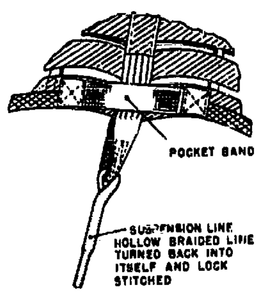
Canopy Diameter	Suspended
8 ft.	4000 lb.
32 ft.	(Aircraft dec
44 ft.	(Aircraft dec











1.3 RIBBON PARACHUTE CANOPIES.

1.3.1 FIST RIBBON CANOPY.

1.3.1.1 Canopy Design. This canopy is of flat circular design and composed of concentric ribbons, supported by a number of radial ribbons and smaller semiradial supporting tapes.

1.3.1.2 Drag Coefficient of the Canopy. The drag coefficient c_{D_0} ranges between 0.45 and 0.55, depending on design, size, and applications. For preliminary design purposes, a c_{D_0} value of 0.5 is generally used.

1.3.1.3 Stability of the Canopy. This canopy is very stable. Oscillations in free air reach a maximum of ±5 degrees.

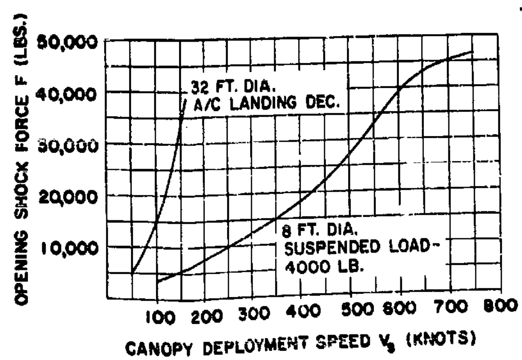
1.3.1.4 Opening Shock. For infinite mass conditions, the opening shock is approximately 1.05.

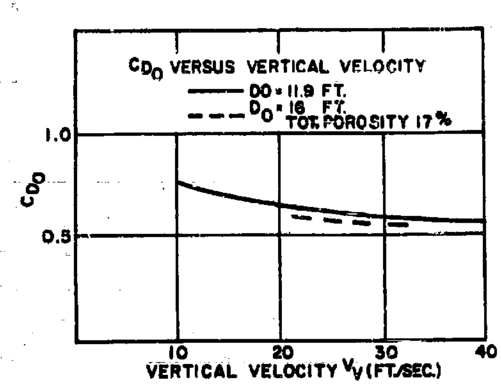
1.3.1.5 Application. This parachute canopy is especially adaptable for deceleration applications. It may also be used in applications where good stability, drag, and high-speed deployment are required.

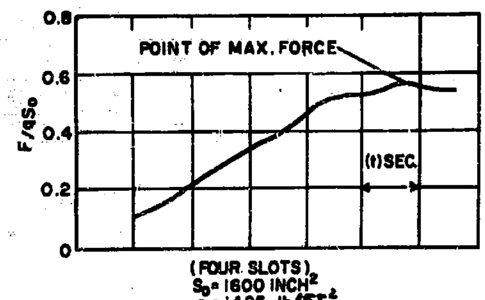
1.3.1.6 Opening Reliability and Speed Limitations. This canopy is relatively slow in opening. Opening reliability depends on specific design parameters. Safe deployment speed limitations for specific canopy configurations and nearly infinite mass conditions are as follows:

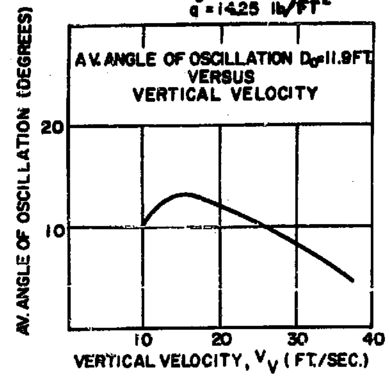
Canopy Diameter	Suspended Load	Canopy Material	Lines	Deployment Speed
8 ft.	4000 lb.	1000 lb. nylon ribbon	6000 lb.	750 knots
32 ft.	(Aircraft deceleration)	300 lb. nylon ribbon	2250 lb.	160 knots
44 ft.	(Aircraft deceleration)	300 lb. nylon ribbon	3000 lb.	195 knots

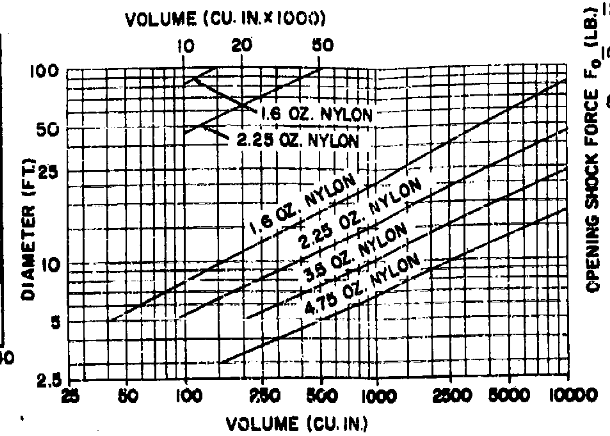
1.3.1.7 Remarks. This canopy type is relatively easy to manufacture. For specific design parameters, see Chapter V.

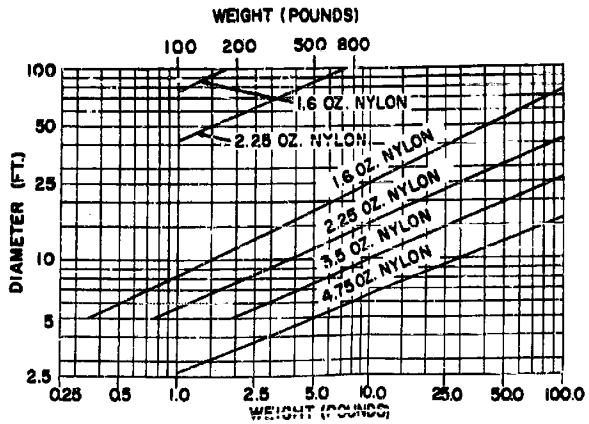


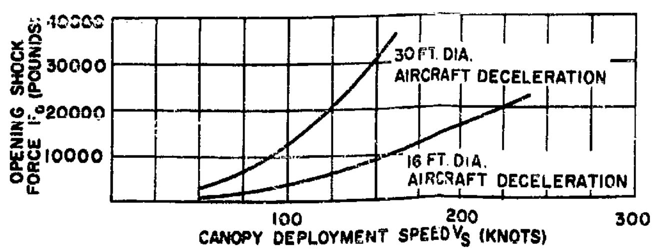


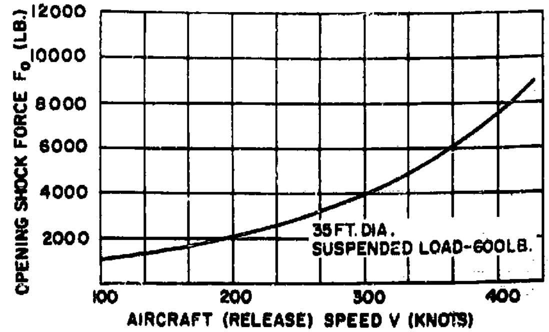


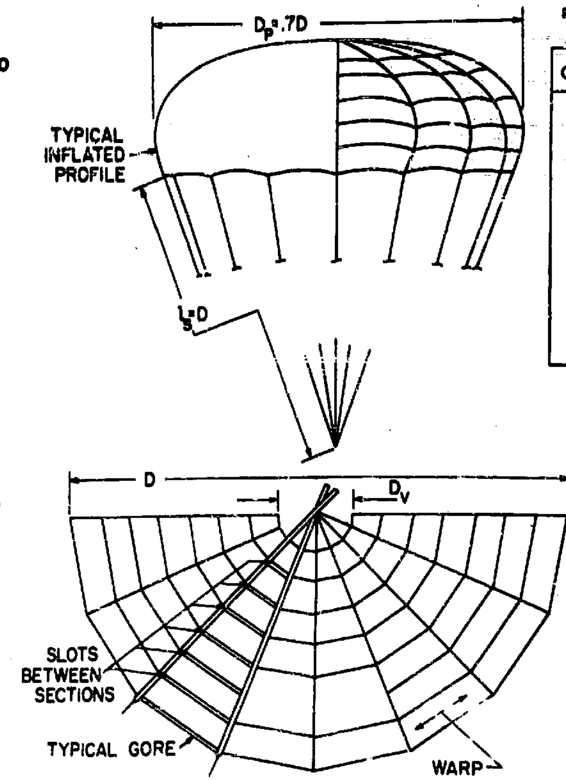












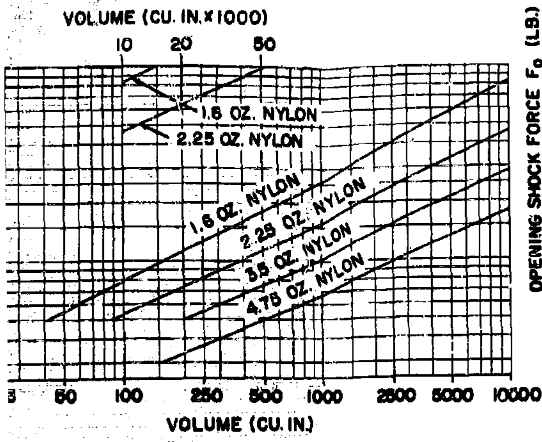
1.3.2 RING SLOT CANOPY.

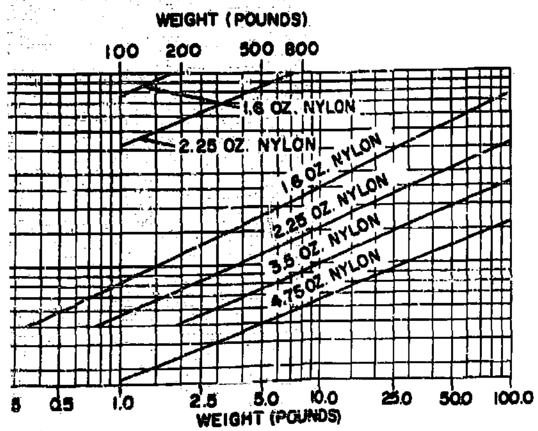
1.3.2.1 Canopy Design. This canopy is circular design. The canopy consists concentric cloth strips with interven slots. The number of slots varies, de upon canopy diameter.

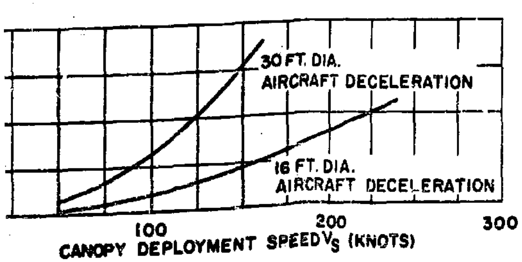
1.3.2.2 Drag Coefficient of the Canop drag coefficient c_{D_0} varies between 0 0.65, depending upon speed, design, and tion. For preliminary calculations, value of 0.55 is generally used.

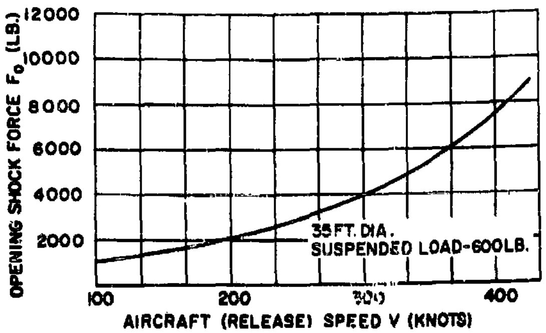
1.3.2.3 Stability of the Canopy. Most are very stable. Maximum oscillation are approximately ±7 degrees.

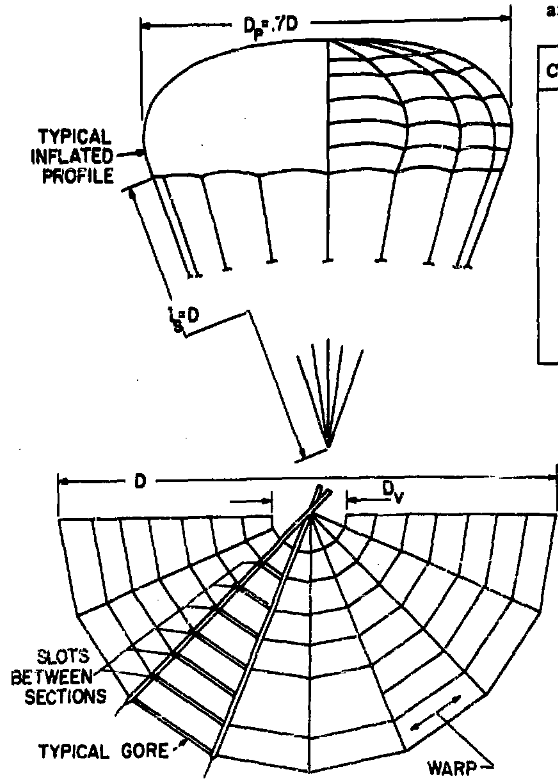
Canopy Diameter	Suspended Load
16 ft.	(Aircraft deceleratic
16 ft.	(Aircraft deceleratic
20 ft.	(Aircraft deceleratio
24 ft.	(Aircraft deceleratio
30 ft.	(Aircraft deceleratio
34 ft. (reefed)	450 lb.
64 ft. (reefed)	1850 lb.











1.3.2 RING SLOT CANOPY.

1.3.2.1 Canopy Design. This canopy is of flat circular design. The canopy consists of wide concentric cloth strips with intervening air slots. The number of slots varies, depending upon canopy diameter.

1.3.2.2 Drag Coefficient of the Canopy. The drag coefficient c_{D_o} varies between 0.45 and 0.65, depending upon speed, design, and utilization. For preliminary calculations, a c_{D_o} value of 0.55 is generally used.

1.3.2.3 Stability of the Canopy. Most designs are very stable. Maximum oscillation angles are approximately ±7 degrees.

1.3.2.4 Opening Shock. For infinite mass conditions, the opening shock factor is approximately 1.05.

1.3.2.5 Application. These canopies may be used for deceleration or cargo extraction applications. They are also satisfactory as descent or recovery parachute canopies, when less oscillation and higher deployment speed than that found in the flat circular type canopy is desired.

1.3.2.6 Opening Reliability and Speed Limitations. Opening reliability is comparable to that of FIST ribbon canopy designs. Safe deployment speeds for some specific canopy and suspended load configurations are as follows:

Canopy Diameter	Suspended Load	Canopy Material	Lines	Deployment Speed
16 ft.	(Aircraft deceleration)	2.25 oz. nylon	1500 lb.	190 knots
16 ft.	(Aircraft deceleration)	3.5 oz. nylon	2250 lb.	240 knots
20 ft.	(Aircraft deceleration)	2.25 + 3.5 oz. nylon	1500 lb.	170 knots
24 ft.	(Aircraft deceleration)	2.25 + 3.5 oz. nylon	1500 lb.	150 knots
30 ft.	(Aircraft deceleration)	3.5 + 4.75 oz. nylon	2250 lb.	160 knots
34 ft. (reefed)	450 lb.	2.25 + 4.75 oz. nylon	1500 lb.	500 knots
64 ft. (reefed)	1850 lb.	1.1 + 2.25 oz. nylon	375 lb.	250 knots

1.3.2.7 Remarks. At the present time, this parachute canopy is more costly to manufacture than the flat circular type canopy. It is less expensive to manufacture than the FIST ribbon type canopy, and is being substituted for the FIST ribbon type for some applications.

1.4 MISCELLANEOUS CANOPIES

1.4.1 GENERAL. Many model and full-size canopies of shapes other than those discussed, or variations of those shapes, have been built and tested. Some, such as the steerable parachutes, compare reasonably with the type upon which the modification was based. On others, however, insufficient data are available to draw any firm conclusions about their performance.

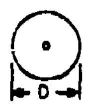
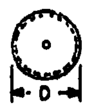
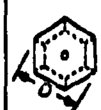
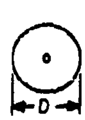
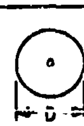
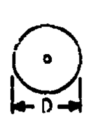
1.4.2 AIRFOIL CANOPY. This canopy is designed as a portion of a sphere cut by two parallel planes and, as projected, takes the form of a circular plate, with the smaller diameter at the vent. Its c_{D_0} is approximately 0.85. The maximum deployment speed at which little or no damage occurs is low compared to those of other designs. In addition, the design of the suspension line system is very critical and, to date, can be determined only by drop test. This, together with the greater care needed in packing, makes this type canopy of interest only for very special applications. Its bulk and weight values are slightly higher than those of a comparable flat circular parachute.

1.4.3 FLAT NONCIRCULAR CANOPY. Canopies of this general design are constructed as a flat plate. They may be square, triangular, or of any other shape. Coefficient of drag is sometimes higher than that of a flat circular canopy, but packing difficulties are numerous. The opening shock is generally as high as that of a flat circular canopy. Bulk and weight are generally the same as, or slightly less than, the bulk and weight of comparable flat circular canopies. Some of these designs are remarkably stable. Reliability is equal to, or less than, that of flat circular canopies. Manufacturing costs are higher.

1.4.4 WAKO CANOPY. As originally designed, this canopy is constructed as a hemisphere composed of a number of ribbons starting at the skirt, running tangent to the vent, then to the opposite skirt, in opposing pairs. This arrangement is repeated around the canopy as many times as required, and it results in a geodetic-type construction. Its bulk and weight are higher than those of the FIST ribbon type canopy. Like all ribbon canopies, it depends upon slow opening for its low opening shock characteristics, and upon high geometrical porosity for its stability. A variation of this canopy, developed by WADC, is similar in design, but is constructed as a flat circle.

1.4.5 STEERABLE PARACHUTE CANOPIES. Steerable parachute canopies generally have been derived by modification of flat circular type canopies. A discussion of steerable canopies may be found in Chapter III, Section 1, Personnel Parachutes.

1.5 AVERAGE PERFORMANCE CHARACTERISTICS OF PARACHUTE CANOPIES.

	Canopy Type	Constructed Shape		Diameter Ratios		Drag Coefficient		Opening Shock Factor (Infinite Mass)	Stability	
		Plan View	Profile View	D_p/D	D_o/D	Range	Average (Prelim. Design)		Remarks	Aver. Angle of Oscill.
SOLID TEXTILE	Flat Circular			.70	1.000	C_{D_o} 0.65-0.90	C_{D_o} 0.75	> 2.0	unstable	±30°
SOLID TEXTILE	Extended Skirt			~.76	1.24	C_{D_o} 0.65-0.85	C_{D_o} 0.70	~1.8	unstable	±20°
SOLID TEXTILE	Guide Surface (Stabilization)			~1.0	1.60 for 10 gores	C_D 0.8-1.0	C_D 0.95	~1.1	stable	±1°
SOLID TEXTILE	Guide Surface (Ribless)			~.95	1.51 for 10 gores	C_D 0.75-0.85	C_D 0.80	1.1-1.3	stable	±1°
SOLID TEXTILE	Guide Surface (Personnel)			~.73	1.15	C_{D_o} 0.68-0.82	C_{D_o} 0.72	~1.2	stable	±7°
SOLID TEXTILE	Rotafoil			.91	.95	C_{D_o} 0.63-0.90	C_{D_o} 0.78	~1.05	stable	±8°
SOLID TEXTILE	Shaped (Conical)			~.70	1.08	C_{D_o} 0.68-0.95	C_{D_o} 0.80	~1.8	unstable	±20°
RIBBON	FIST			.67	1.000	C_{D_o} 0.45-0.55	C_{D_o} 0.50	~1.05	stable	±3°
RIBBON	Ring Slot			.70	1.000	C_{D_o} 0.45-0.65	C_{D_o} 0.55	~1.05	stable	±7°

CHAPTER II

SECTION 2

OPENING AND DEPLOYMENT OF PARACHUTES

2.1 GENERAL.

Opening characteristics of a parachute may be loosely defined to include all the consecutive motions of a parachute system operation, from the instant of initiation of deployment until complete inflation. Deployment is a term covering the extension of the canopy and suspension lines from the stowed position to the beginning of inflation of the canopy.

2.2 OPENING METHODS.

2.2.1 STATIC LINE. Most small cargo parachutes and troop main parachutes are opened by a static-line assembly, which consists of the following items:

a. Static-line snap
b. Static line
c. Break cord.

Operation is as follows: The static-line snap is firmly attached to a body whose differential velocity and mass will be sufficient to break a pack open, or to withdraw ripcord pins. The static line, upon full extension, begins to deploy the parachute canopy, which is attached to the static line by means of a break cord. Strength of the break cord depends upon the area of the main canopy to be deployed before separation of the canopy and static line occurs. It is possible to withdraw ripcord pins or break packing cords by static line, and thus free a pilot parachute for deployment of the main canopy.

2.2.2 RIPCORD. Personnel parachutes usually are opened either by a manually operated ripcord or by an automatic opening device pulling the ripcord. In many models, this ripcord, withdrawing from a set of cones, allows pack opening springs or elastics to withdraw the covers of a pack, freeing a pilot chute that is capable of deploying the main canopy. A newer method employs locking loops, which replace the cones. Elastics are not used; the force of a coilspring-loaded pilot chute is sufficient to snap open the pack and eject the pilot chute.

Another method sometimes employed to close and open a parachute pack is the use of a zipper installed along the full length of the side flaps at the edges where they meet at the longitudinal centerline of the pack. Packs utilizing this closing method are called "chain closed" packs and, to date, are still in the experimental stage. Opening of the chain closed pack is accomplished by pulling the zipper slider completely free of the zipper, allowing flat springs installed in the side flaps to peel back these flaps, and disengage the zipper teeth in the process.

2.2.3 EJECTION. Parachutes are often ejected into the airstream by powder charges or springs. Deployment can then be accomplished by a pilot chute.

2.3 DEPLOYMENT OF PARACHUTES.

2.3.1 SYSTEM REQUISITES. A good deployment system must have certain objectives.

2.3.1.1 There must be reliable deployment through the design operating range.

2.3.1.2 Malfunctions during the deployment must be prevented. If canopies are allowed to deploy as a result of their own drag, it is possible for the canopy to become inverted, or badly burned by friction. Deployment systems should control the movement of the deploying canopy to prevent side loads on the skirt area of the parachute before completion of suspension line stretch and to allow orderly deployment of the canopy in a plane relative to the relative air.

2.3.1.3 Reduction of snatch force must be provided for. Snatch force can be simply defined as the force required to accelerate the mass of a fully deployed but incompletely open canopy from its final velocity at the completion of the line stretch to the velocity of the suspended load. Snatch force depends upon differential velocity between load and uninflated canopy at the completion of line stretch, and also upon the effective drag area of the pilot chute and main canopy. For instance, a partially open canopy

with a drag area of 20 square feet will impose a considerably higher snatch force on a suspended load than a deployed but uninflated canopy with a drag area of 2 square feet. Canopies with large drag areas not only impose a pseudo-opening shock snatch force, but also increase the differential velocity between load and canopy during the deployment. Good high-speed deployment must, therefore, present the smallest system drag area that is consistent with orderly deployment, until line stretch is complete. Thereafter, the deployment system must provide completely reliable release of the canopy for inflation.

2.3.1.4 Low bulk and weight are desirable and necessary.

2.3.2 DEPLOYMENT METHODS.

2.3.2.1 Simple Pilot Chute. This method is used with most ripcord-operated assemblies. It is very reliable for personnel emergency parachutes. It consists of a small canopy and suspension line system. In some cases, the pilot chute is spring loaded for positive ejection. It is attached to the apex of the main canopy. Upon inflation, it withdraws the main canopy from the pack and guides it for positive and proper inflation.

2.3.2.2 Simple Static Line. Static-line opening and static-line deployment usually are employed in conjunction with each other. After the pack is opened, the apex of the canopy is held until sufficient drag is exerted on the deploying canopy to break the cord attaching the apex to the static line. Unfortunately, the rate of deployment of the parachute often exceeds the speed of the dropped load. This permits a "sail" to develop, during which inversions and semi-inversions can readily form. The extent and duration of the "sail" is governed primarily by the strength of the break cord. Strong break cords tend to straighten the sail. If break cords are too weak, canopies are not withdrawn from the pack sufficiently for orderly deployment, and further deployment depends only upon the drag area of the exposed canopy. Static-line deployment of an exposed and uncontrolled canopy is not reliable or desirable at high speeds or with large canopies.

2.3.2.3 Pilot Chute and Sleeve or Bag. This method entails the use of a long cloth sleeve, or cone, of a length equal to the constructed radius of a parachute canopy, and of a very small base. The sleeve is constructed with a locking flap at the base, through which there are projected two retaining loops from the side of the cone. Into these two loops the suspension lines of the canopy are placed. The remaining folds of suspension lines are placed in retaining loops that are sewed to the outside of the locking flap. Thus, the canopy cannot leave the sleeve until the last loop has been removed from the sleeve at the completion of the line-stretch. This method has a number of advantages. Snatch forces are reduced, since no inflation of the canopy takes place until after deployment. Malfunctions are reduced considerably, because of the correct placement of the canopy in relation to the suspended load before opening. Damage to the canopy from friction or from protrusions is reduced because of the protection afforded by the sleeve. One disadvantage is the possible occurrence of friction burns during exceptionally high-speed removal of the canopy from the sleeve. In certain instances, this can be overcome by use of double thickness sleeve, where the inner portion of the sleeve can be pulled inside out by the deploying canopy to prevent friction burns.

The deployment bag method is similar to the sleeve type in that the canopy remains in the bag until the lines are extended. When used with a static line, its reliability is very high; with pilot chute deployment, the reliability is dependent upon straight-line deployment. In some applications, two pilot chutes are used simultaneously; one is designed to withstand deployment at high speed, the other for positive low-speed application.

2.3.2.4 Other Methods. There are a number of combination deployment methods, such as combination of static-line pack opening with pilot-chute deployment; static-line pack opening with sleeve deployment by pilot chute; static-line pack opening with bag deployment of main parachute; static-line opening with pilot-chute deployment and sleeve or bag; and use of jettisonable objects as anchors for static lines. This last method is used in high-speed drop test bombs, in which the decelerating mass of the jettisoned tail is used to anchor a static line, which opens the rear-mounted pack in the bomb, and also deploys the parachute canopy. The jettisonable tail actually can be classed as a pilot chute. Pilot chute deployment by means of ejector guns, and deployment of canopies with the aid of blast bags, are being used for various applications.

2.3.3 GENERAL CONSIDERATIONS FOR DEPLOYMENT SYSTEMS. The pack and packing

method used have a great deal of influence upon the deployment of parachute canopies. Position of the pack in relation to the relative air also is critical. Generally, it may be stated that consideration must be given to the blanketing effect of the suspended load on the pack and pilot chute, to twisting, tumbling, or spinning of the suspended load and consequent snagging and burning of the canopy during deployment, and to "wadding," in which the canopy deploys as a ball or mass. Usually, "wadding" is caused by the use of improper static-line arrangements, pilot chutes of insufficient drag area, or improper positioning of the pack, so that upon opening, the full pressure of the relative air is directed against the entire folded canopy.

2.3.4 PACKS AND PACKING.

2.3.4.1 PACKS. Packs serve the purpose of protecting the canopy, pilot chute, or other deployment device from disarrangement and damage during handling as well as operation. In some installations, packs are integral with the suspended load, have flush openings, and may incorporate ejection devices to initiate or aid deployment.

2.3.4.2 Requirements for Satisfactory Packs.

a. A nonrestricting opening, or an opening that is not exceeded by any internal cross-sectional area perpendicular to the direction of deployment.
b. A simple design, without sharp corners, recesses, or sides tapered inward toward the area open for deployment.
c. A smooth, low-friction interior, free from protrusions, snags, or obstructions to canopy or lines.
d. Provision for attachment and storage of pilot chutes, if used, and for pilot-chute bridle cords.
e. Provision for deployment bag or sleeve.
f. Provision for incremental retention of canopy and lines in proper arrangement without shifting until deployed.
g. Rapid and complete opening to prevent damage to the canopy during first phases of deployment.
h. Provision for the attachment of the parachute to the load.
i. Positioning of the pack to preclude snagging on any portion of the suspended load during deployment.
j. Provision either for passage of the suspension lines or risers through the pack to the main load-carrying members (which can be accomplished through the base or sides of the pack), or for placement of main fittings within the pack, and shielding these fittings to prevent snagging or tangling with canopy or suspension lines.
k. For certain applications, metal packs are satisfactory, if they are smooth and are provided with beaded or bevelled edges at the area open for deployment.

CHAPTER III

PARACHUTE APPLICATIONS

The advent of high-performance jet aircraft and missiles makes it impossible at the present time to standardize on a few types of parachutes that will perform satisfactorily for all applications and conditions. In practically every application, there must be a compromise between drag, strength, deployment, speed, stability, and cost of production. Present applications call for such a wide range in speed of deployment, altitude of deployment, desirable stability, and drag that only infrequently is it possible to select a parachute used successfully for one type of application and find it satisfactory for another.

Types of Applications. There are five general applications for parachutes:

a. Personnel
b. Cargo
c. Stabilization
d. Guided Missile and Drone Recovery
e. Aircraft Deceleration

CHAPTER III

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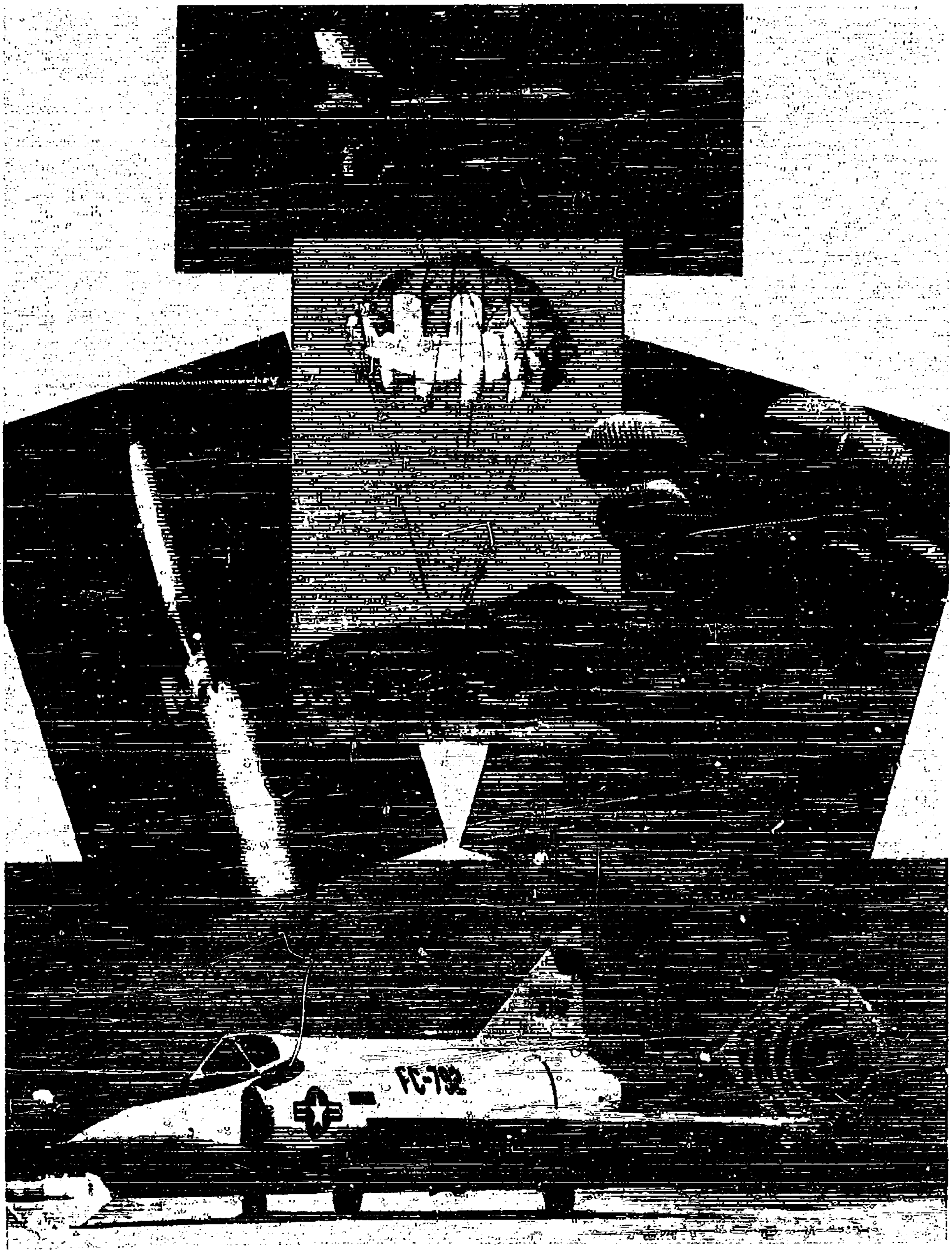

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CHAPTER III

SECTION I

PERSONNEL PARACHUTES

1.1 GENERAL.

Personnel parachutes may be used for emergency escape, troop dropping, or air rescue. In this handbook, we are considering as personnel parachutes only those which lower an individual directly. Parachutes for lowering a capsule, platform, or other devices containing personnel may be constructed on the lines of those discussed under Cargo, Guided Missile and Drone Recovery, or Aircraft Deceleration; however, reliability requirements must meet those discussed here.

1.2 REQUIREMENTS.

1.2.1 MANDATORY. All personnel parachutes must meet these requirements. With the exception of reliability, this list is not necessarily in the order of importance.

a. Absolute reliability, both opening and actuation, whether automatic or manual.
b. Rapid opening.
c. Rate of descent of no more than 25 ft. per sec. for a 300-lb. jumper (usually achieved by high drag coefficient to keep bulk to a minimum).
d. Low bulk and weight (refer to c. above).
e. Comfortable, light, properly designed harness.
f. Provision for fast release of parachute canopy from harness or person.
g. Tolerable snatch and opening forces at presumed maximum speed and altitude of deployment.
h. Stability within ±20° for emergency use and ±10° for premeditated jumping.

1.2.2 DESIRABLE. Additional desirable requirements and features for personnel parachute systems are:

a. Low initial cost.
b. Resistance to damage during use and recovery.
c. Ease of repair.
d. Ease of packing.
e. A pack without corners or protuberances, properly positioned in order not to be subject to damage or snagging preceding or during deployment.
f. Adaptability to automatic operation.

1.2.3 CONSIDERATIONS. The designer of personnel parachutes must take into consideration many design requisites. He must know these facts:

a. Rate of descent desired.
b. Allotted load limits.
c. Amount of desirable stability.
d. Primary use — emergency escape, troop dropping, or air rescue.
e. Bulk and weight requirements.
f. Speed range.
g. Altitude range.
h. Opening method.
i. Provision for or desirability of ejection seat stabilization.

In most cases, knowledge of a. through f. is sufficient to make a quick and easy determination of type and size of parachute canopy. However, if g., h., and i. impose unusual conditions, it will be necessary to investigate further. For instance, ejection seat stabilization may or may not be a design requirement, but in any case it will be a consideration in design.

1.3 PERSONNEL PARACHUTE COMPONENTS.

1.3.1 CANOPIES. Selection of one of three canopy styles, the flat circular type, flat extended skirt, or the personnel guide surface type, meets or can be developed to meet the majority of needs for deployment at subsonic speeds. Where the characteristics of those canopies do not meet a specific requirement, it will be necessary to consider the data available on other types, as shown in Chapter II. For deployment at speeds in the transonic and supersonic range, it will probably be necessary to use a capsule or other protective device, since present research indicates the probability of injury from wind blast and/or deceleration effects at those speeds. For such high-speed

emergency escape applications, the types covered under Cargo, Guided Missile and Drone Recovery, or Aircraft Deceleration should be considered.

1.3.1.1 Flat Circular Canopy. (See Figure 3-1-1.) This type (basic diameter 28 ft., paratrooper reserve parachute canopy 24 ft.) has a high coefficient of drag, is relatively simple to produce, is sufficiently stable for most personnel applications, is reliable at speeds up to 200 knots, is relatively simple to pack and repair, and is light and compact. It may be deployed by ripcord or static line or a combination of both. Its chief disadvantage is the limitation of deployment speed and lack of stability for certain applications.

1.3.1.2 Flat Extended Skirt Canopy. (See Figure 3-1-2.) This type of parachute canopy may be deployed at higher speeds than the flat circular type and has better stability. It is relatively simple to produce, pack, and repair. The 35-ft. nominal diameter 10 percent flat extended skirt type MC-1 is in standard use at the present time. It is an integral part of the type T-10 parachute.

1.3.1.3 Personnel Guide Surface Canopy. (See Figure 3-1-3.) This 30-ft. nominal diameter parachute canopy seems to offer the most promise for a high deployment speed personnel parachute. Present designs utilize a shaped (for example, conical) canopy similar to the flat circular type, but with four gores removed. The guide surfaces are created by extending alternate roof panels. This canopy has excellent stability for personnel applications. Opening shock is considerably less than that for the flat circular type. Further development may increase its present maximum safe bail-out speed of 375 knots. Construction is relatively simple. This canopy offers an increase in performance without an increase in weight, bulk, or undue manufacturing cost. It is reliable.

A comparison of average opening force versus aircraft release velocity for the C-9, MC-1, and C-11 parachute canopies is presented in Figure 3-1-4. Typical force versus time histories of canopy inflation for these types are shown in Figure 3-1-5. Various characteristics for parachutes, including the three types of canopies discussed above, are presented in Figure 3-1-6.

1.3.1.4 Steerable Parachute Canopies. Steerable parachute canopies are mainly used for dropping rescue personnel and fire fighters. They are not used as personnel emergency parachutes, because they can be used to advantage only by experienced jumpers. They are not used by paratroopers because of danger of mid-air collision through loss or misuse of control.

All steerable parachute canopies are so constructed that entrapped air is expelled in a manner which produces a jet thrust. The jet thrust generally results in a glide of about 5 knots. Turning control is achieved by warping the canopy to deflect the jet. On some types it is possible to achieve a rate of turn of about 60 degrees per second.

1.3.1.4.1 Derry Slot. (See Figure 3-1-7.) The E-1 parachute canopy is steerable by virtue of its slots (see sketch). The "Derry" slots are placed symmetrically aft of the center of the canopy and to the left and right of the fore and aft center. A pull on either of the two guidelines tends to deform the slot on that side. The jet thrust is then reversed, and the canopy rotates toward the side of the pulled guideline.

1.3.1.4.2 Slit Skirt. (See Figure 3-1-8.) The MC-1 becomes steerable with incorporation of a V slot approximately 6 feet long in the rearmost gore. The skirt hem does not cross the open slot. Reinforcement at the apex of the slot is necessary. When the aft risers are pulled on the side toward which it is desired to turn, the skirt on that side is forced to a lower position than the skirt on the other side of the slot. The resulting direction of jet flow causes the canopy to rotate. This parachute canopy has proved to have stability, rate of descent, and opening shock comparable to that of the conventional MC-1.

1.3.1.4.3 Other Types. In addition to the two steerable parachute canopies mentioned, there are a number that are or have been undergoing tests. The parachute canopy shown in Figure 3-1-9 is a standard MC-1 canopy modified by portholes and slip risers. This arrangement provides a very rapid rate of turn. Figure 3-1-10 is a Hart type parachute canopy. The extended gores are on the fore part of the canopy. Figure 3-1-11 shows an MC-1 parachute modified with tilted extensions. Figure 3-1-12 is another modification of an MC-1 parachute canopy.

1.3.2 AUTOMATIC OPENING PARACHUTES. With the exception of parachutes used in certain types of aircraft, such as liaison airplanes,

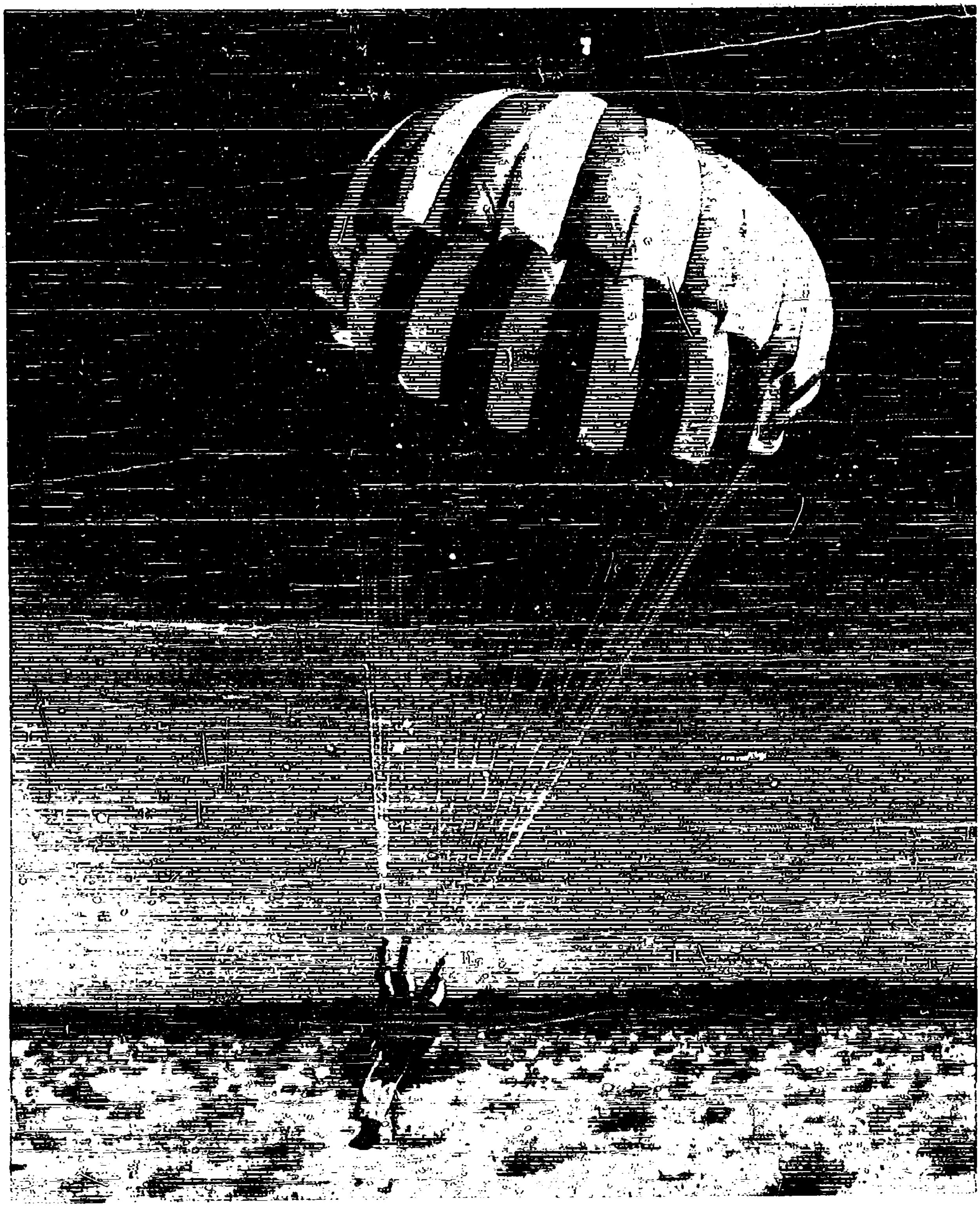


Figure 3-1-1. Personnel Parachute Canopy Type C-9

Figure 3-1-2. Personnel Parachute Canopy, Type MC-1

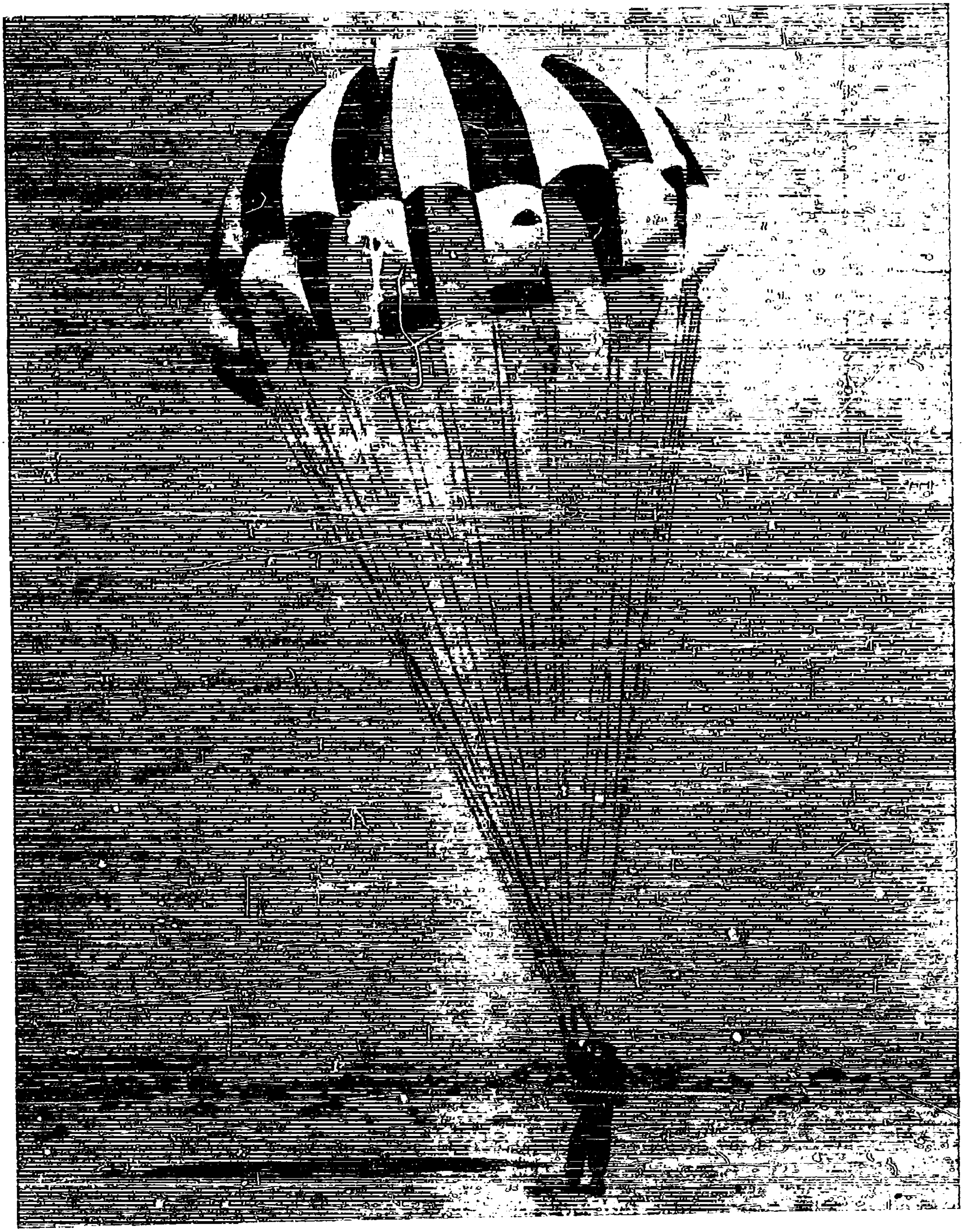


Figure 3-1-3. Personnel Parachute Canopy, Type C-11

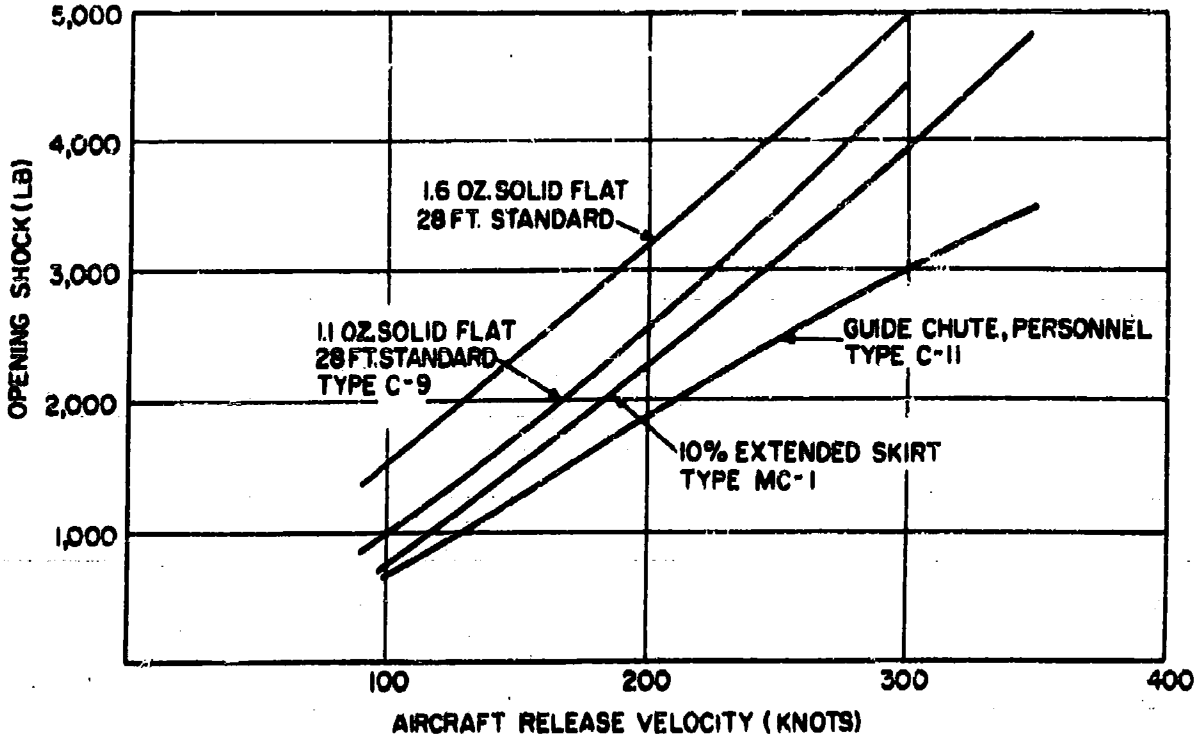


Figure 3-1-4. Average Opening Force Versus Aircraft Release Velocity for Types C-9, MC-1, and C-11 Parachute Canopies

helicopters, and certain transport type aircraft, all personnel parachutes should be designed for the installation of an automatic ripcord release. The release should be mounted inside the parachute pack, so that:

a. Comfort of the parachute wearer is not affected
b. The release is easily accessible for inspection, servicing, and installation
c. Automatic actuation of the ripcord is reliable
d. The arming knob or handle of the release is suitably mounted and accessible to either hand.

The automatic parachute enables the wearer to escape above a preset altitude, arm his automatic release, and initiate parachute deployment automatically at a safe and predetermined level above the terrain. If the wearer escapes from the aircraft below an altitude equivalent to the preset altitude value of the automatic release, parachute deployment should be initiated automatically after a predetermined delay time to allow for sufficient speed delay and avoid high or excessive opening shock forces. Different views of the parachute pack type B-5, incorporating an automatic ripcord release, oxygen bottle, C-11 canopy, and harness are shown in Figure 3-1-13.

1.3.3 PARACHUTE PACK. The parachute pack shall suitably house, protect, and mount the parachute canopy on the person. It is mandatory that the pack open with absolute reliability, both automatically and manually, at the time the ripcord is actuated, and permit uninterrupted deployment of the canopy. Such operation must take place under the extremes of environmental and handling conditions imposed in service. The use of metal ribs or stiffeners in the pack design should be minimized to reduce weight and maintain wearing comfort. The pack should mount firmly and form-fit the body to minimize fouling on aircraft equipment and seats. The integration of the pack with other personal equipment the person may be required to wear, and with the overall escape system in the aircraft, is highly important and will influence the design and configuration of the pack.

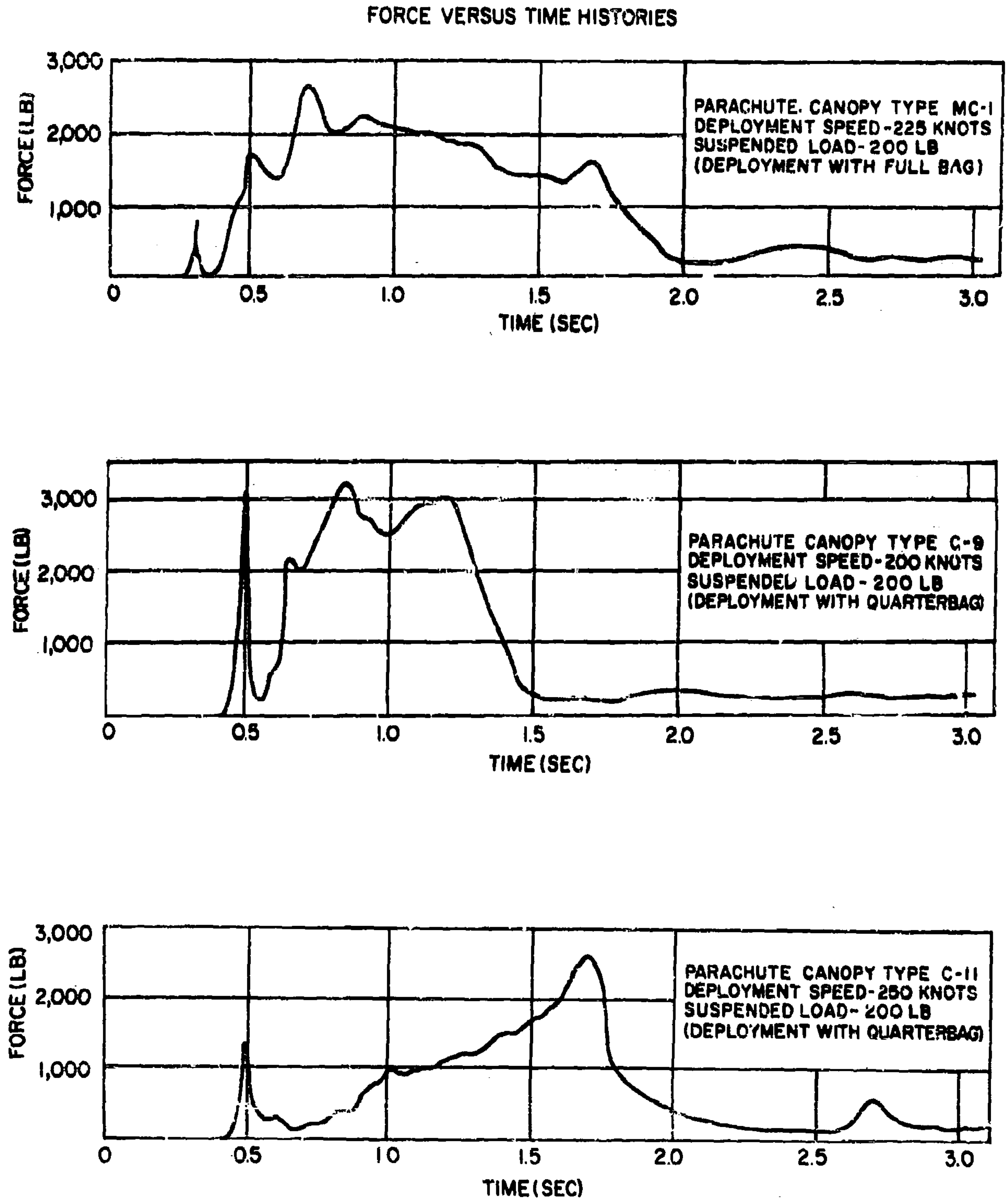


Figure 3-1-5. Typical Force Versus Time Histories of Canopy Inflation for Types C-9, MC-1, and C-11 Parachute Canopies

Figure 3-1-6. Parachute Characteristics

COMPONENT PARTS	PARACHUTE ASSEMBLY (BACK STYLE) Assy No. 50C 7024-8	Assy No. 50C 7024-10	PARACHUTE ASSEMBLY TYPE T-10	PARACHUTE ASSEMBLY (BACK STYLE, AUTOMATIC) Assy. No. 50C 7024-12
Harness Assembly (1) material (2) release (3) fittings	Nylon webbing type XIII J-1 canopy release Quick adjust. V-rings and snaps		Cotton or nylon webbing 3-prong, quick, type B-2A Quick adjust. leg strap adapters, D-rings for attaching reserve parachute	Nylon webbing type XIII J-1 canopy release Quick adjust. V-rings and snaps
Main Parachute Pack (1) dimensions (2) material	26" x 15" x 5" Nylon cloth, plied yarn		20" x 12" x 6" 10 oz. cotton duck	25.5" x 16" x 6" Nylon cloth, plied yarn
Canopy (1) diameter (2) material (3) suspension lines (4) gores (5) connection links	Type C-9 28' (flat circular) 1.1 oz. nylon cloth, orange and white 14 each – 75.3' lengths, running continuous from connector to connector (550 lb. T.S.) 28 Separable connector links		Type MC-1 35' (nominal) 1.1 oz. camouflaged ripstop nylon 30 each (25.5', 375 lb. T.S.) 30 (shaped) 4 replaceable	Type C-11 30' (nominal with guide extensions) 1.1 oz. nylon ripstop, orange and white 12 ea. – 89.45', continuous from connector to connector (375 lb. T.S.) 24 Separable connector links
Deployment Bag (1) dimensions (2) material (3) static line (4) stow loops	None		18" x 12" x 5" (full bag) 8.5 oz. cotton twill 15" nylon webbing type XIII 2 rows (11 loops each)	20" x 13" x 11" (quarter bag) Nylon cloth, plied yarn None 2 rows (10 loops each)
Reserve Parachute Pack (1) dimensions (2) material	None		17" x 11" x 8" 10 oz. cotton duck	None
Canopy (1) diameter (2) material (3) suspension lines (4) gores			24' (flat circular) 1.1 oz. camouflaged ripstop nylon 24 each (20', 550 lb. T.S.) 24	
Ripcord Assembly	Flexible steel cable with grip and locking pins		Steel wire handle with 6.75" metal cable (RESERVE ONLY)	Flexible steel cable with grip and locking pins
Automatic Release	None	Type F-1A	None	Type F-1A
Weight of Parachute	26 lb.	29 lb.	39 lb.	26 lb. (with automatic release and oxygen bottle)
Primary Application	Emergency escape		Paratrooper	Emergency escape

Figure 3-1-7. E-1 Steerable Parachute Canopy

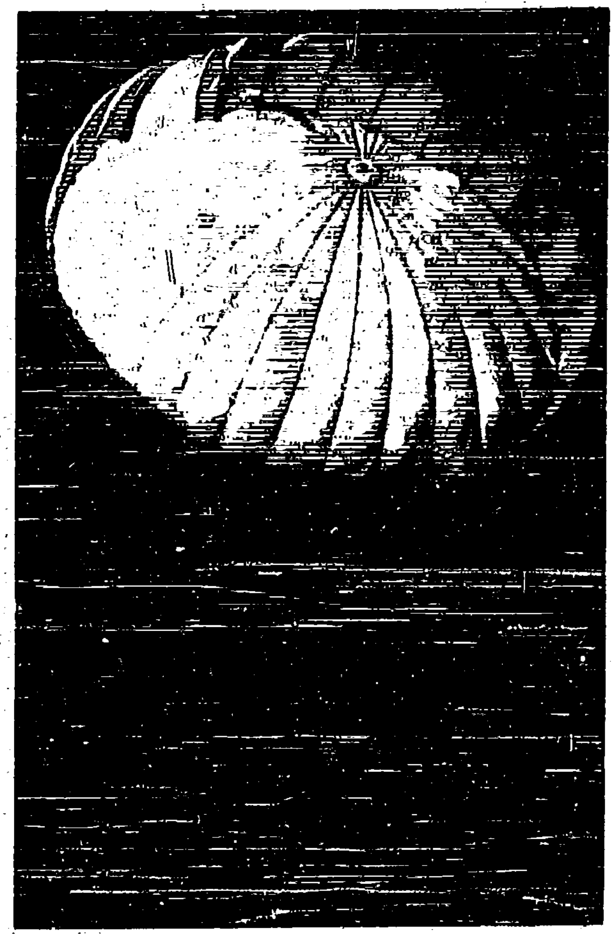


Figure 3-1-8. Steerable Parachute Canopy (Modified MC-1)

1.3.4 HARNESS.

1.3.4.1 Purpose. The parachute harness worn by the jumper is employed first to transmit the parachute opening forces to the wearer in such a manner that he is not injured, and second to satisfactorily support the wearer during the descent. The harness, consisting primarily of webbings and associated hardware, may be connected directly to the suspension lines by use of links. It is preferred that risers be employed to connect the suspension lines to the harness. The support during descent should be such that the wearer's vertical axis is approximately perpendicular to the earth's surface.

1.3.4.1.1 On personnel emergency type parachutes, packs and harnesses are usually maintained as one unit. This necessitates the wearer's carrying the parachute, harness, and attached personal equipment when on the ground. A more desirable arrangement, which is being given considerable attention at the present time, is the separation of the harness from the pack and other attached personal equipment while on the ground. By this arrangement, the parachute and attached personal equipment is kept in the aircraft. The pilot or other air crew member wears only the harness until he enters the aircraft, at which time he attaches the chute and personal equipment to the harness. This system can be so arranged that the straps attaching the parachute pack to the harness also serve as the aircraft safety straps. The portion of the parachute system remaining in the cockpit at all times can be hooked up for automatic disconnection from the seat during an emergency ejection. Survival kits and other personal equipment can also be attached to that portion remaining in the aircraft.

1.3.4.1.2 A series of drop tests have given an indication of the maximum percentage of total force that may be exerted at various points in conventional personnel harnesses. Figure

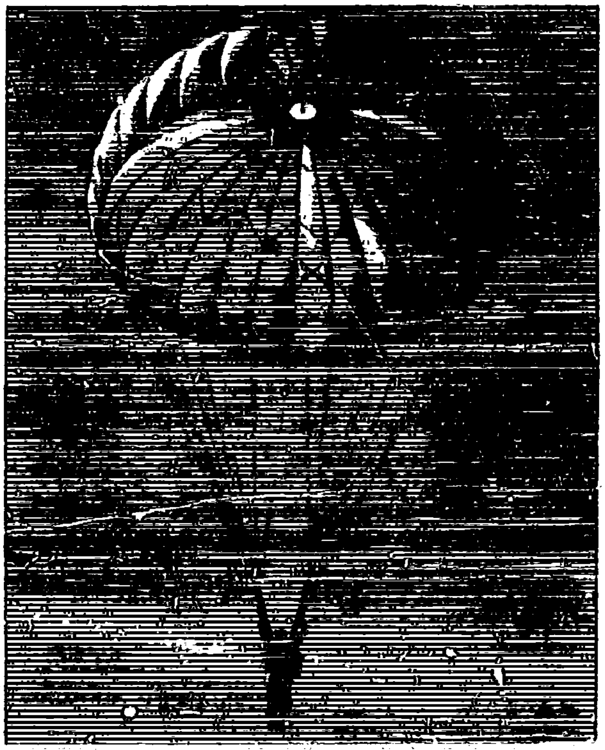


Figure 3-1-9. MC-1 with Portholes and Slip Risers

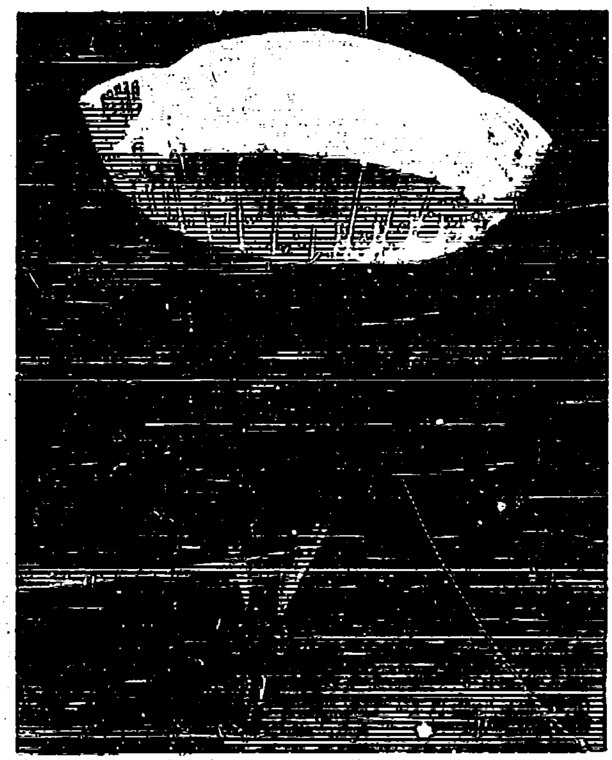


Figure 3-1-11. MC-1 with Tilted Extensions

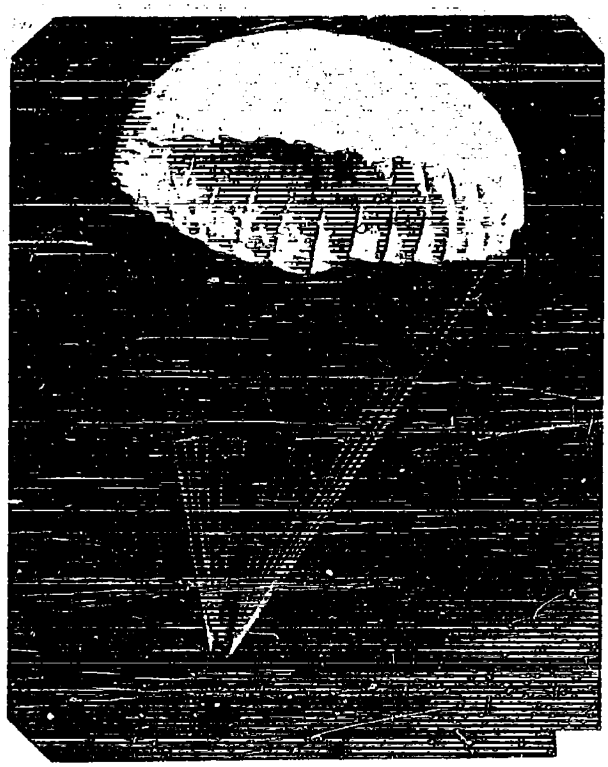


Figure 3-1-10. Hart Type Parachute Canopy

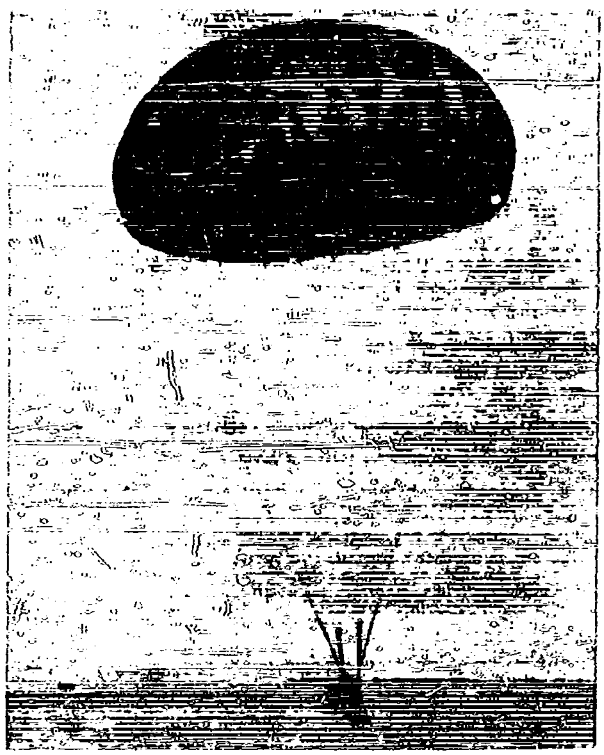


Figure 3-1-12. Single Porthole Steerable (Modified MC-1) Canopy

Figure 3-1-13. Parachute Pack Type B-5

3-1-14 lists these forces and locations for both cotton and nylon harnesses.

1.3.4.1.3 Many attempts have been made to improve present harness design. One is the use of netting with low-strength intertwining strands. A big drawback to such a system is the difficulty of providing adjustment to desirable limits, and of designing around extreme elongation.

1.3.4.2 General Considerations for Harness Design.

a. Harnesses must be constructed so that adjustment can be accomplished by the user and repairs can easily be made by personnel of operating units and overhaul bases.
b. A safety factor of 1.5 must be maintained throughout all portions of the harness. Technical Memorandum Report WCLE-53-292 gives guidance on the relative strength of the various component straps and fittings of the harness necessary to meet requirements.
c. Design should be such that no temporary sewing or tacking is necessary.
d. The harness must encompass the body in such a manner that its basic function of retaining the body at the terminus of the parachute canopy suspension system is absolutely and inherently secure.
e. The suspension straps and harness must not interfere with normal vision or seriously hamper movement required for parachute canopy manipulation during descent or at ground impact.
f. The harness must incorporate a suitable connection for a parachute canopy. On present designs, four risers are attached to the harness to provide proper suspension and suitable transmission of the maximum parachute opening force. The connection of the riser straps and the harness should be located 1 to 2 inches below the collarbone of the wearer.
g. The harness should be simple in design, with an absolute minimum of parts that may become entangled, twisted, or interposed with one another, forcing the wearer to realign the parts for donning.
h. The harness should be so designed that an individual may don the assembly while in a seated position. While in that seated position, the wearer should be able to adjust the harness.
i. The harness must incorporate a method whereby the wearer can remove the harness quickly and easily by operating all connectors with one hand.
j. The number of adjustment points required to accomplish fitting of the harness should be kept to a minimum. The adjustment points should be visible to the wearer when seated.
k. The adjustment points must not hamper or prevent actuation of the ripcord and/or automatic parachute arming knob on the accessible front area of the harness when worn.
l. The harness must be so designed that faulty or careless adjustment will not permit it to fall from the wearer's shoulders during canopy deployment or opening.
m. The harness must be quickly and easily adjustable without roping or jamming of the webbings in the adjustment fittings. The size of the harness must be indicated by a visible marking, so that the size to which the harness is adjusted will be readily seen at a glance.
n. Unless individually sized, the harness must be readily and quickly adjustable to a suitable fit for individual personnel sizes varying from 5 feet 2 inches to 6 feet 6 inches in height and 110 to 250 pounds in weight, with or without standard Air Force winter flight clothing.
o. The harness must not cause discomfort to the wearer resulting from limited area body contact and pressure points, or cause uncomfortable restriction from bulky protrusions, which may invite snagging on other personal equipment or the aircraft seat.
p. There must be no strap adjusters, connectors, or metal fittings against the wearer's back when the harness is worn. Metal fittings must not contact the wearer's face, neck, or head during canopy opening or descent.

1.4 CANOPY DEPLOYMENT.

There are four types of deployment used with personnel parachutes: (1) pilot chute, (2) static line, (3) pilot chute and quarter bag, and (4)

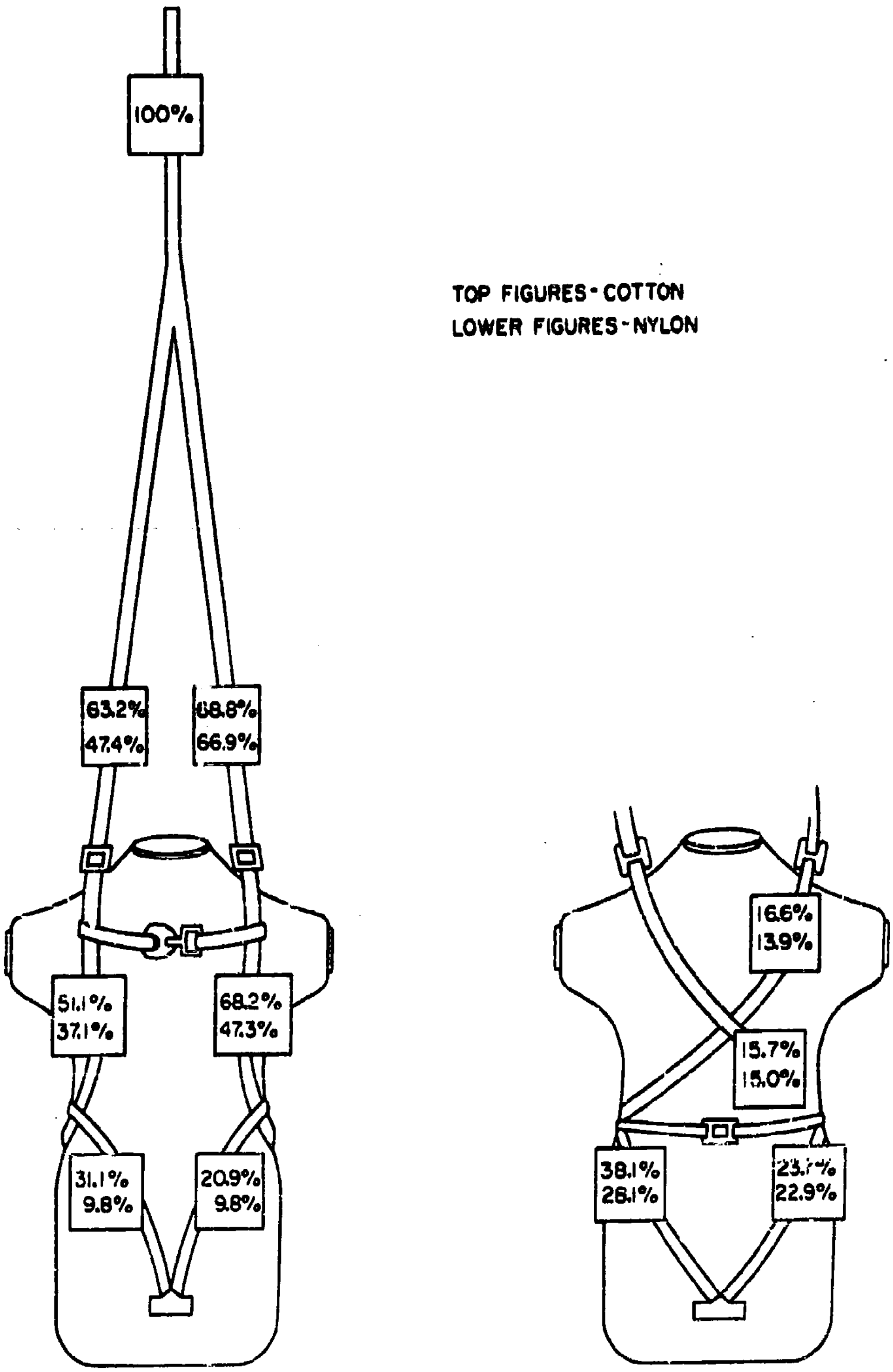


Figure 3-1-14. Maximum Force Percentages Measured on a Parachute Harness During Canopy Opening

static line and deployment bag. Number (1) has been used for many years for personnel emergency parachutes. Number (2) is still used by the air rescue service, but it has generally been replaced by number (4) for other premeditated jumping. See Chapter II for further information on deployment systems. Figure 3-1-15 shows the deployment of a type T-10 parachute and a correlation of static line force to state of deployment. Note the deployment bag and the smooth, straight deployment of the suspension lines.

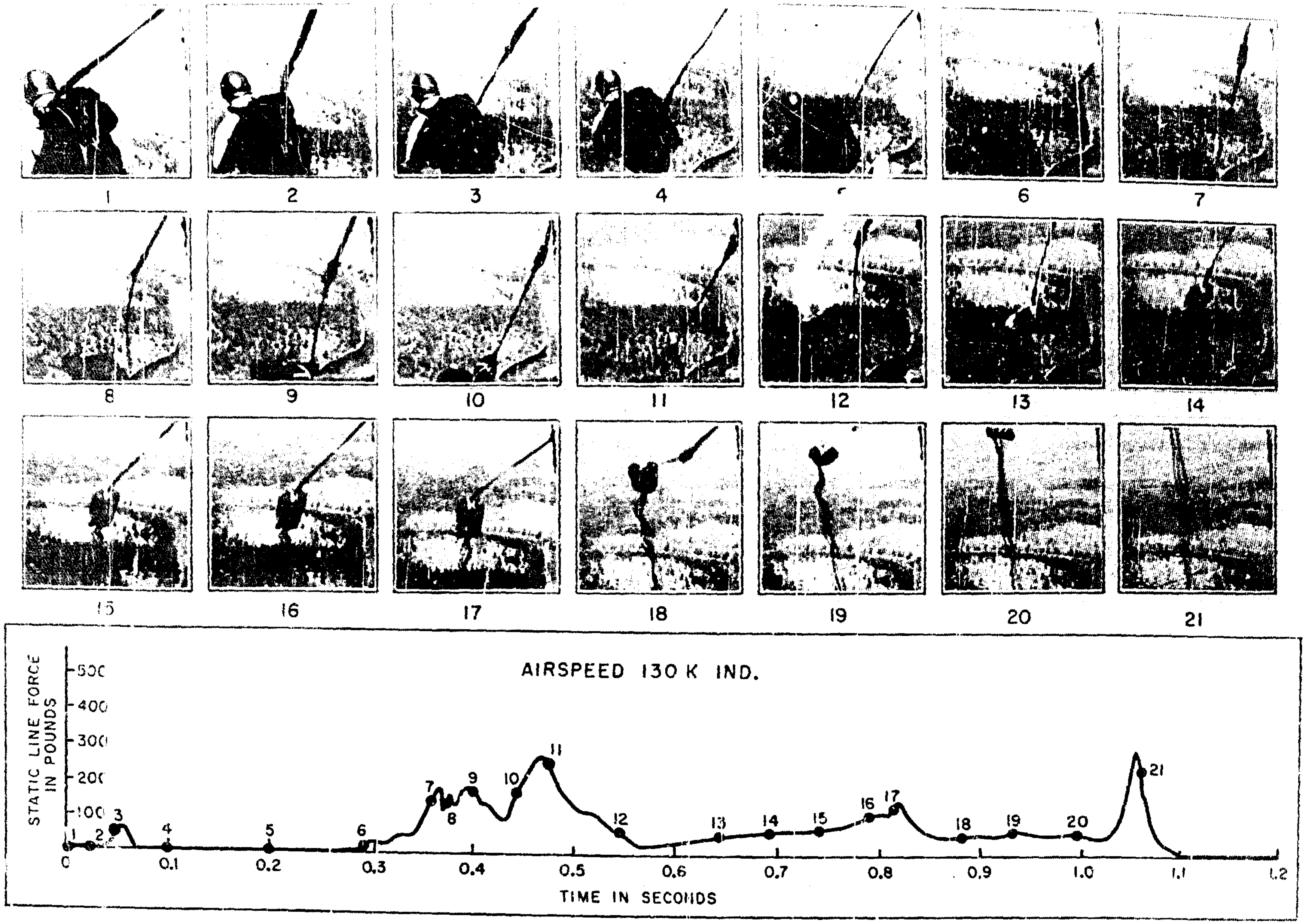


Figure 3-1-15. Correlation of Static Line Force to State of Deployment of a Type T-10 Parachute (Nylon Line)

CHAPTER III

SECTION 2

AERIAL DELIVERY

2.1 GENERAL.

2.1.1 Aerial delivery systems require the use of parachutes for aerial delivery of vital supplies and equipment in operational condition in support of combat operations and resupply missions. Present aerial delivery systems are designed for cargoes weighing from 100 to 25,000 pounds. The primary objective of the aerial delivery system is the capability of air-dropping a variety of vehicles, weapons, heavy cargo, and miscellaneous supplies to any strategic locality in such a manner that they will be usable within a minimum amount of time and with minimum hazard to personnel involved.

2.1.2 An aerial delivery system must include the restraining, releasing, and moving of a compatible cargo load safely and positively out of an aircraft in flight at the pilot's command. The system generally consists of: a platform or container to hold the cargo; a parachute system capable of producing the proper rate of descent without damaging shock loads; a decelerating system to assure minimum damage to the cargo at ground impact; and, where applicable, platform antitoppling devices. A parachute canopy ground release is provided to prevent load turnover or drag of parachuted supplies during high ground wind conditions. The aerial delivery sequence of a type D4 bulldozer is shown in Figure 3-2-1.

2.2 AIRCRAFT SYSTEMS.

2.2.1 AIRCRAFT TYPES. At the present time, the following cargo aircraft are considered suitable for aerial delivery purposes: the C-97, C-119, C-123, C-130, and C-124. The C-119 is equipped for overhead monorail delivery, as well as for delivering equipment by means of extraction from the aft end of the cargo compartment using an extraction parachute. All current cargo aircraft are propeller-driven and are designed for relatively low dropping speeds in the range between 110 and 150 knots. It is possible that in the next few years situations may develop in which it is necessary to devise high-speed aerial delivery systems for use with future design cargo aircraft. At the present time, however, most aerial delivery systems are for operation at launching speeds of up to 130 knots.

2.2.2 METHOD OF EJECTION. Two general methods of cargo ejection are used in today's cargo type aircraft.

2.2.2.1 Gravity System. In this method, the cargo or cargo container (see Figure 3-2-2) rolls from the aircraft. It utilizes a floor-secured roller system. The roller conveyor is sloped by change of the attitude of the aircraft to permit the cargo to move by gravity once the restraint is removed.

2.2.2.2 Power Ejection. The other general system is the power ejection system. One type utilizes an overhead monorail and numerous trolleys suspending individual containers up to 500 pounds in gross weight. The trolleys are moved along the overhead monorail by a motor-driven cable. When the trolley reaches the release point, a trigger opens a shackle to release the load. In this system, a typical load of twenty 500-pound bundles may be released in a period of 7 to 8 seconds. A second type of power ejection system utilizes an extraction parachute as a source of power for movement of loads from the aircraft, as shown in Figure 3-2-3.

2.2.3 RESTRAINING SYSTEMS. The design of the restraining system must be based on aircraft design load factors, as given in specification MIL-S-5705, which outlined general "g" values in all possible directions. When skid type platforms are used, the primary restraints are removed manually by releasing the tie-downs shortly before the drop (see Figure 3-2-4). With stressed type platforms, restraint is automatically removed by action of the extraction parachute during the ejection cycle. On the overhead bundle system, Figure 3-2-5, the cable controls the fore and aft movement. Lateral container movement is restricted by side curtains or similar means.

Figure 3-2-1. Aerial Delivery of a Type D4 Bulldozer

Figure 3-2-2. A-22 Container Drop from a C-123 Aircraft

2.3 OVERALL DESIGN.

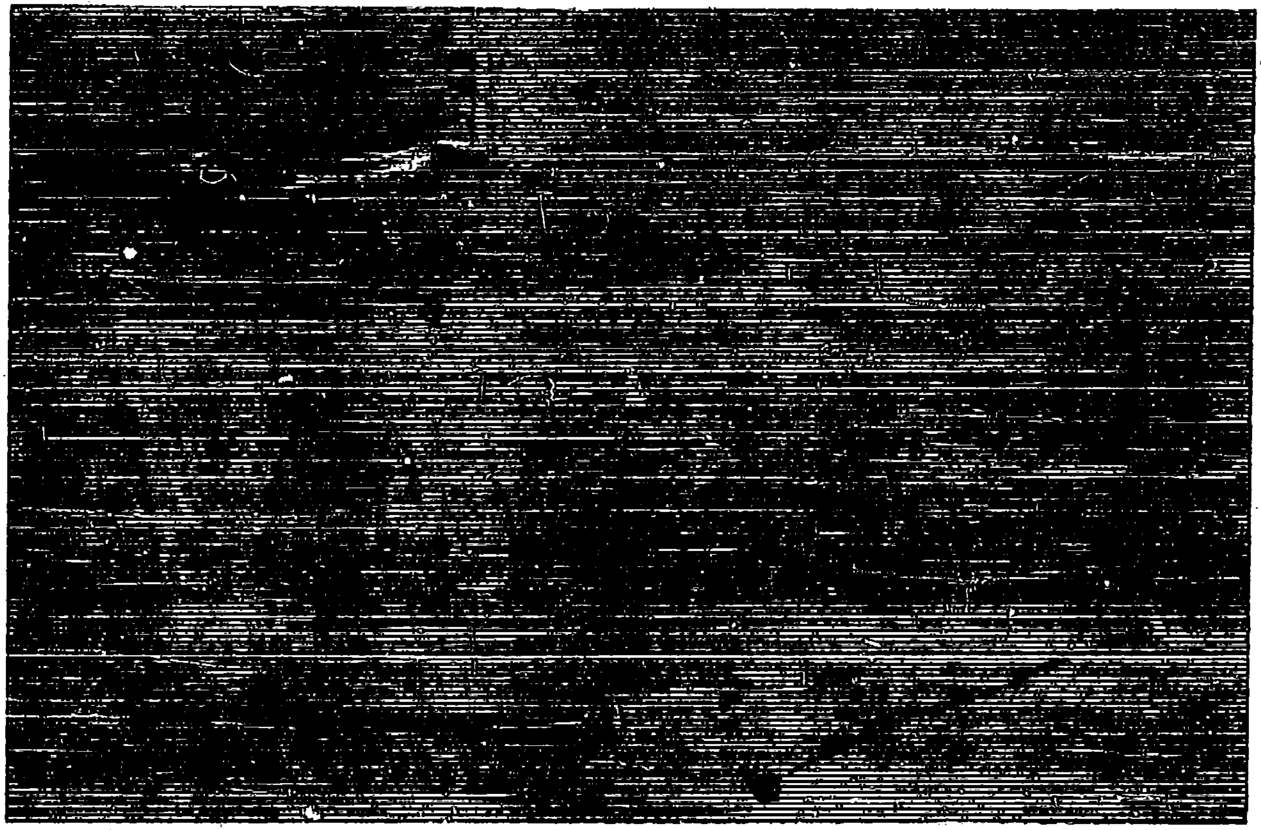
2.3.1 OBJECTIVES. In most instances, the design of an aerial delivery system is based on getting the cargo to the ground in the least possible time without damage to the cargo, applying the most economical and practical methods. The least possible time is desirable for maximum drop accuracy, minimum dispersion of drop loads, and minimum effect of wind drift. This decreases the time during which the cargo is vulnerable to enemy fire and decreases the time in which the enemy may pinpoint the area of drop. Theoretically, the ideal system would not employ any deceleration device, but would absorb landing shock to prevent damage to cargo. Practically, however, size, weight, and cost of the shock absorbing devices required prohibit their use for bulky or heavy objects. Shock absorbing devices on platforms and containers, in conjunction with parachutes, have great advantages. The stabilizing effect of the parachute canopy permits the container to be so constructed that it need absorb impact shocks basically in only one direction. Present designs of aerial delivery systems strive to achieve the best possible compromise between a landing impact absorbing system and a rate of descent low enough to hold the design of the shock absorbing devices to reasonable bulk, weight, and cost.

2.3.2 GENERAL CONSIDERATIONS FOR DESIGN OF AN AERIAL DELIVERY SYSTEM.

2.3.2.1 Durability. Many aerial delivery drops take place in an area where it is possible to recover the parachute. It is therefore desirable to employ parachutes and hardware that will resist damage under ordinary, anticipated conditions.

2.3.2.2 Ease of Manufacture and Low Cost. Wherever possible, parachute design should be simple for ease of manufacture. Low cost designs adapt themselves to a high rate of production.

2.3.2.3 Critical Materials. At the present time, cargo canopies utilize nylon, rayon, and cotton muslin. Rayon is used in the 24-ft. diameter G-1A, 12-ft. diameter G-7, and 8-ft. diameter G-8 parachutes. Cotton muslin cloth is used in



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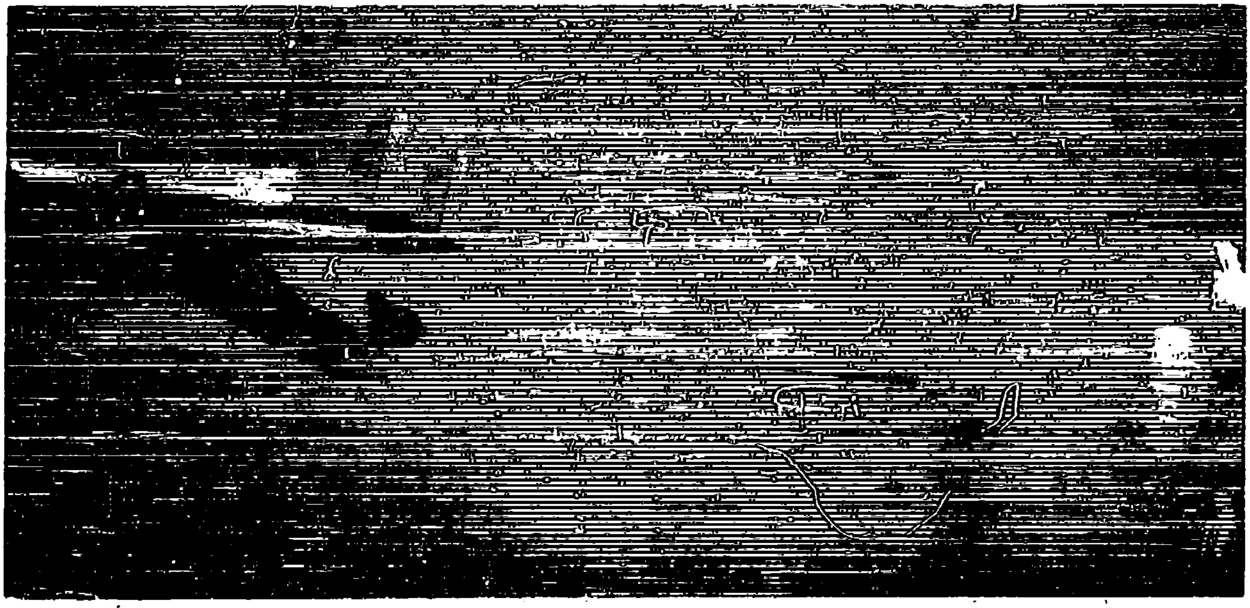


Figure 3-2-3. Cargo Extraction

Figure 3-2-4. Tie-Down Restraint

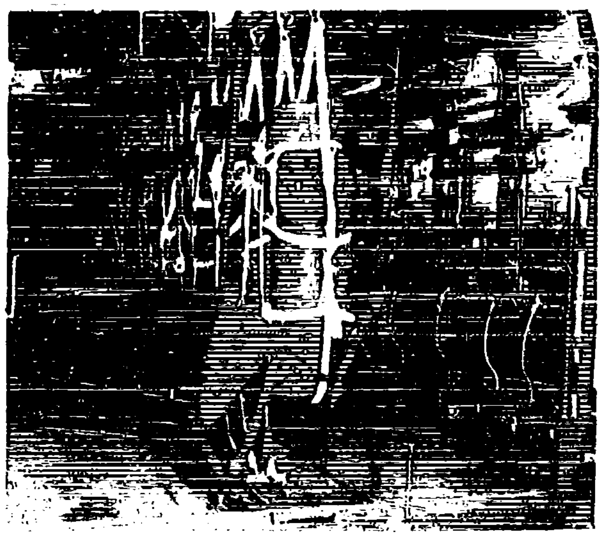


Figure 3-2-5. Power Ejection — Overhead Bundle System

the G-13 hemispherical parachute. Nylon materials are used in the construction of the 64-ft. diameter G-12 and the 100-ft. diameter G-11A parachutes.

2.3.2.4 Reliability of Inflation. Aerial delivery parachute canopies do not have to meet the reliability requirements of personnel chutes. However, for accurate dropping, they must be dependable, must have predictable inflation characteristics, and must be consistent in performance.

2.3.2.5 Ease of Maintenance. Ease of maintenance is principally a function of design simplicity. Aerial delivery parachute canopies are subject to damage not only by ground and object contact but also through lack of attention after completion of drop or through mishandling by inexperience personnel.

2.3.2.6 Rate of Descent. In general, the rate of descent of 25-ft. per second will be strived for. However, faster rates of descent will be used for cargoes that resist damage at the higher impact shocks and for special aerial delivery application.

2.3.2.7 Stability. An oscillation of ±10° is permissible for most cargo container drops. A higher degree of stability is required for aerial delivery systems equipped with pneumatic shock absorbers.

2.3.2.8 Opening Shock. For most aerial delivery systems, opening shock is not of primary concern, except that it be held sufficiently low and within the limitations of the design load criteria of the parachute system.

2.3.2.9 Bulk and Weight. Bulk and weight is of particular importance for ease of handling by ground personnel. In most cases, however, the bulk of the parachute is not critical due to the aircraft space available.

2.3.2.10 Environment. Aerial delivery canopies are often packed and stored for a considerable time in areas of high humidity, relatively high temperatures, or extreme cold. When the environmental conditions for a specific design are expected to be unusual, it will be necessary to select the proper material and/or make provision for special protective packing.

2.3.3 OTHER DESIGN CONSIDERATIONS.

a. Maximum tolerable shock loads and the direction of those shock loads in relation to the cargo.
b. Maximum vertical fall distance permissible before terminal velocity is reached.
c. Specific stability requirements for the particular cargo being dropped.
d. Rate of descent desirable during any stage or reefed canopy condition.
e. Suspension design in relation to load cg and attitude for landing.
f. Conformation to available space in aircraft prior to and during exit.
g. Anticipated range of launching speed and altitude for drop.
h. The anticipated aircraft to be utilized and its characteristics and capabilities in regard to load extraction or ejection.
i. The minimum weight possible for the system, including platforms or containers and parachutes.
j. Determination of whether to use expendable or reusable containers or platforms.
k. The maintaining of the cg of the aircraft within controllable limits.
l. The provision for rapid exit to keep dispersion drop area to a minimum.
m. The point of attachment to the structure of the platform for the absorption of opening shock.
n. A deployment system so designed that the load does not get a chance to overturn completely after exit.
o. The stability of the load prior to main canopy deployment.
p. Reliable deployment without complicated deployment system.
q. Selection of proper material in relation to cost and strength.
r. Ease of packing and handling.
s. Low cost of maintenance.

2.4 PARACHUTE CANOPIES.

2.4.1 GENERAL. Single parachute canopies or clusters of them may be used either for extraction or for vertical descent. In general, it is desirable to have canopies with a high drag coefficient, which has a direct bearing on the weight and bulk of the system.

2.4.2 EXTRACTION PARACHUTE CANOPIES. Extraction parachute canopies must be of simple and dependable design. (See Figure 3-2-3.) A particular requisite is that they perform reliably in the wake of the aircraft. Another requisite is very high stability. Parachute canopies now considered satisfactory for extraction purposes are the ring slot and ribbon types. Consideration is being given to a special design of the guide surface canopy that has low opening shock. The advantage of the guide surface canopy lies in its rapid opening characteristics, which would provide better control of the time sequence during extraction. The size of the extraction canopy is determined by the time required to remove the load from the aircraft compartment.

In general, the following extraction parachute canopies are used for cargo extraction during C-119 aerial delivery missions:

a. For cargo loads between 3,500 and 6,000 pounds — 15-foot ring slot canopy (reefed)
b. For cargo loads between 6,000 and 12,000 pounds -- 15-foot ring slot canopy or 16-foot FIST ribbon canopy.
c. For cargo loads between 12,000 and 25,000 pounds — 22-foot ring slot canopy or 24-foot FIST ribbon canopy.

The force required for cargo extraction generally ranges from 50 to 200 percent of the load being extracted. The higher figure is recommended for use when the stability problems of the aircraft are important. Too high an extraction speed prevents the load from rotating sufficiently to permit smooth canopy deployment from the top of the cargo. Too low an extraction speed may permit the cargo to overturn. See Figure 3-2-6. Figure 3-2-7 shows the relation between indicated airspeed, reefing line length, and extraction load. To insure proper inflation, risers must be sufficiently long to minimize the wake effect. The system must be designed to insure that the parachute canopy is so placed during and after inflation that there is no interference with the aircraft structure.

2.4.3 VERTICAL DESCENT PARACHUTE CANOPIES. At the present time, there are four main types of parachute canopies used for aerial delivery systems: the standard flat; the hemispherical, or baseball; the full extended skirt 12 1/2%; and the 35° conical type. Some of their characteristics are shown in Figure 3-2-8. Standard aerial delivery parachutes are presented in Figure 3-2-9. Typical force versus time histories of various diameter aerial delivery canopies are shown in Figure 3-3-10.

A correlation of parachute canopy shape and force developed during canopy deployment and opening of a 150-ft. diameter experimental aerial delivery canopy is presented in Figure 3-2-15.

2.5 CARGO PLATFORMS.

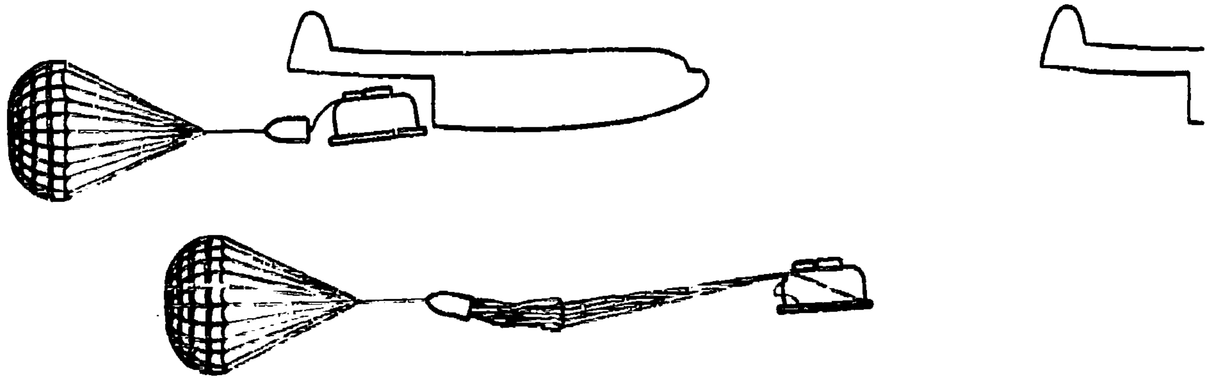
Cargo platforms support the load or serve as a base for a load. Wooden platforms are generally semiexpendable and serve as a base for the load while the load is in the aircraft. After deployment, the parachute system is connected directly to the load and the platform function is reduced to ground shock absorption. Stressed type platforms are constructed of metal. They serve as a base and support for the load while it is in the aircraft, during descent, and upon landing. At the present time, two stressed metal type platforms are undergoing extensive tests. One type (Figure 3-2-16) has side rail restraint, and the other type (Figure 3-2-17) has center rail restraint. See Chapter VIII, Section 2, for a comparison of different platforms and containers.

2.6 DECELERATION AND ANTITOPPLING DEVICES.

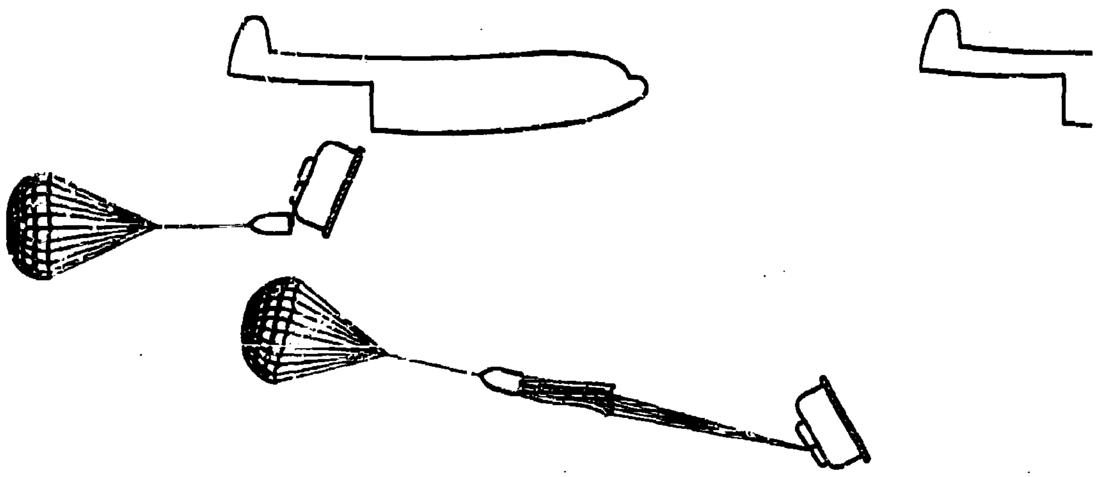
2.6.1 GENERAL. Most aerial delivery systems have been designed to achieve a rate of descent in the neighborhood of 25 ft. per second. The rate of descent may be varied according to the fragility of the cargo, the tactical situation, the accuracy of drop desired, and the efficiency of the ground impact absorption system. The importance of the impact absorption system cannot be overrated. Ground impact forces of up to 100 g have been measured on platforms descending at approximately 30 ft. per second. Various deceleration devices have been employed; the most successful to date for aerial delivery systems is the air bag type. Wind drift can cause damage by making the cargo roll or topple at impact. To avoid such damage, antitoppling devices in the nature of outriggers are employed on the platforms.

2.6.2 DECELERATOR AND ANTITOPPLING SYSTEM. The air bag decelerator or shock absorbing system consists of nylon rubberized barrel-shaped collapsible bags that are approximately 40 inches high, with a major diameter of 34 inches. A series of holes on the bottom surface permits the air to enter the bag, and a rubber flapper valve prevents escape. A rubber blowout diaphragm inserted at the top of each bag is designed to blow out when a predetermined pressure point is reached. On the side rail restraint stressed metal platform, Figure 3-2-16, the bags are laced at the top and bottom to plywood panels. The top panels are attached to brackets fastened to the lower surface of the platform skin. The bags are held in the collapsed, stowed position by the hinged plywood antitoppling doors. These doors are secured by means of cotton cords, which are threaded through time delay cutters. On the center rail restraint stressed metal platform, metal outriggers serve the same function the doors serve on the side rail restraint stressed metal platform. See Figures 3-2-17 and 3-2-18.

2.6.2.1 When the platform is extracted from the aircraft, the cutters are actuated through a 10-second time delay mechanism by a static line from the cutters to the extraction chute fitting. When the cords are cut, the outriggers swing to their open position and allow the air bags to extend downward and fill with air. Upon contact with the ground, the air trapped in the bags is compressed. The top diaphragm is then ruptured by the air pressure, permitting the air to escape through the top



A. TOO HIGH EXTRACTION SPEED—CARGO REMAINS IN NEARLY LEVEL POSITION. INTERFERENCE MAY TAKE PLACE BETWEEN CARGO AND DEPLOYING SUSPENSION SYSTEM. UNEVEN AND EXCESSIVE LOADS MAY BE PLACED ON PARTS OF THE SUSPENSION SYSTEM.



B. TOO LOW AN EXTRACTION SPEED CAUSES CARGO TO ROTATE AND TUMBLE.

C. SEE FIGURE 3-2-1 AND FIGURE 3-2-3 OF THIS SECTION FOR AN EXAMPLE OF CARGO EXTRACTION USING PROPER SIZE EXTRACTION CHUTE.

Figure 3-2-6. Effect of Variation of Extraction Force

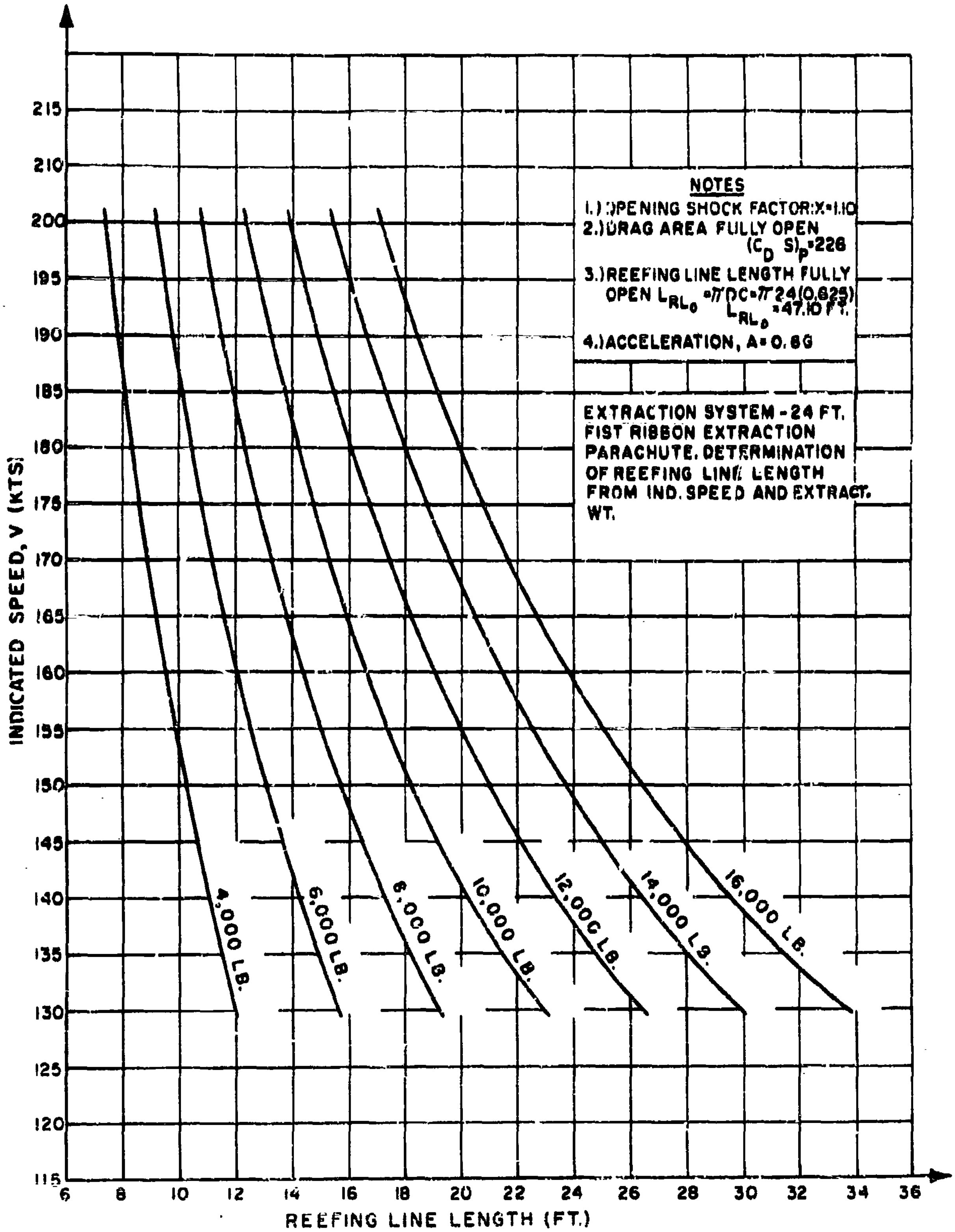


Figure 3-2-7. Reefing Line Length Determination

Figure 3-2-8. Comparison of Various Aerial Delivery Parachutes

Rate of Descent 25 Feet					
Weight (lb.)	Approx. Bulk (cu. ft.)	Load Capability (lb.)	130 Knots Opening Time (sec.)	Flat Circular	Remarks
620	30	12,000	23	200 ft. dia. (Experimental)	See Figure 3-2-11
325	20	8,000	19	150 ft. dia. (Experimental)	
240	11	3,500	10	100 ft. dia. (G-11)	See Figure 3-2-12
120	5	2,200	7.2	64 ft. dia. (G-12)	Figure 3-2-13
25	--	300	2	24 ft. dia. (G-1)	
16	0.3	100	--	12 ft. dia. (G-7)	
45	2.3	500	5	Shaped hemispherical (G-13)	See Figure 3-2-14
11	0.25	200	1 sec at 115 knots	8 ft. dia. (G-8)	

opening. This action results in deceleration of the platform and, therefore, lower impact upon contact of the platform with the ground. The open outriggers or doors also act as an antitopling device when the platform is dropped under wind drift conditions. The additional surface area helps prevent the platform from digging into the soft earth or sand and gives the platform a wider base for increased stability. This feature causes the platform to skid until it comes to a stop, rather than rolling over and damaging the load. (See Figure 3-2-19.) The air bags and doors are semiexpendable and may have to be replaced or repaired after the drop.

2.6.2.2 A typical time history of air bag pressures and platform deceleration obtained during ground impact of a 15-ft. stressed metal type platform with air bags and antitoppling devices is presented in Figure 3-2-20.

2.7 REEFING.

Reefing is not generally used on cargo parachute canopies, because they are designed to withstand opening shock forces at normal deployment velocities. At present, reefing is confined mostly to clusters of large parachute canopies, where the reefing insures that all canopies reach the same stage of inflation [illegible] same time of disreefing, which in turn results in an even deployment (see Figure 3-2-1), and minimizes damage on large parachute canopies. On high-altitude drops, utilizing any size of aerial delivery canopy,

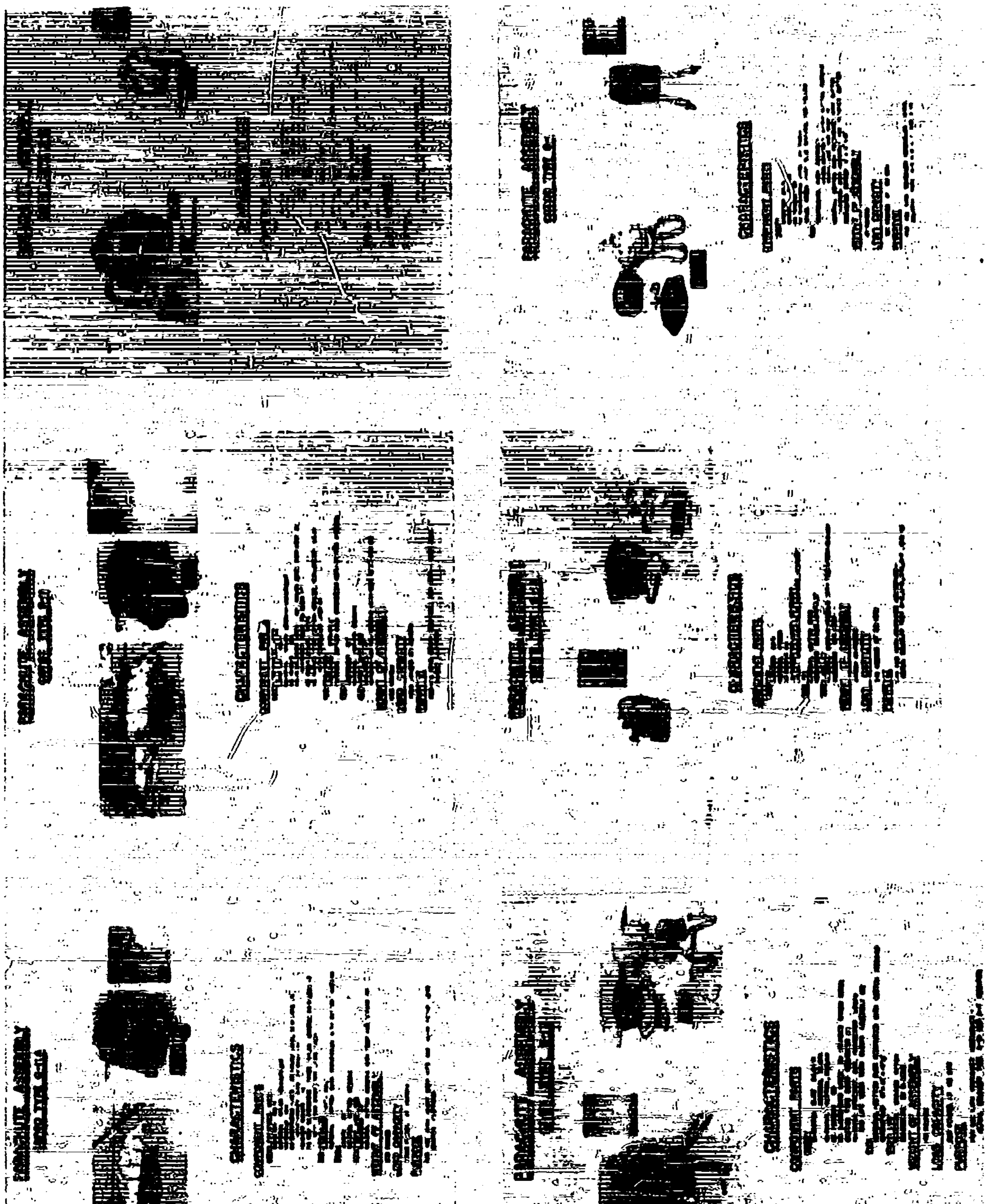


Figure 3-2-9. Standard Aerial Delivery Parachute Systems

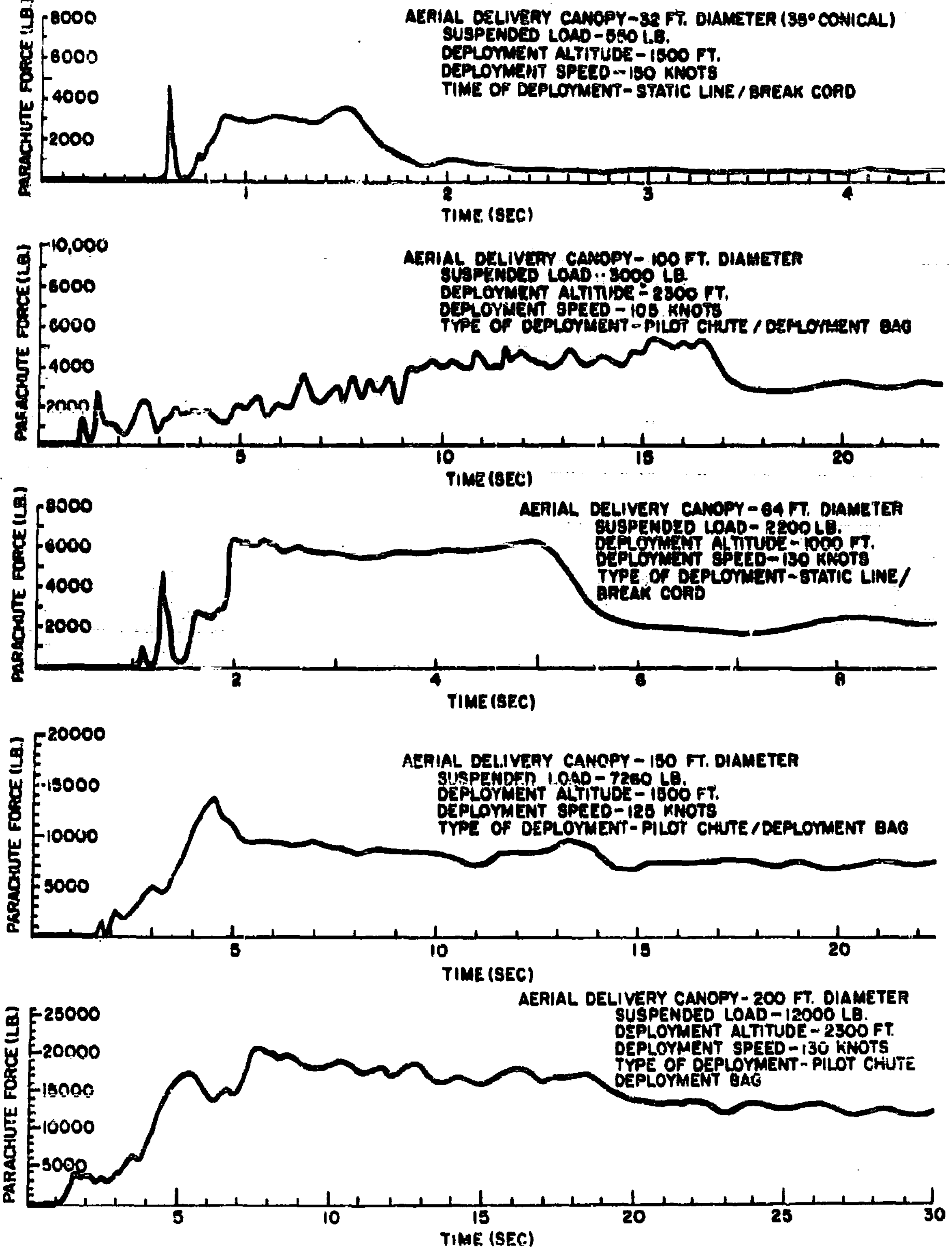


Figure 3-2-10. Typical Force Versus Time Diagram of Aerial Delivery Canopies

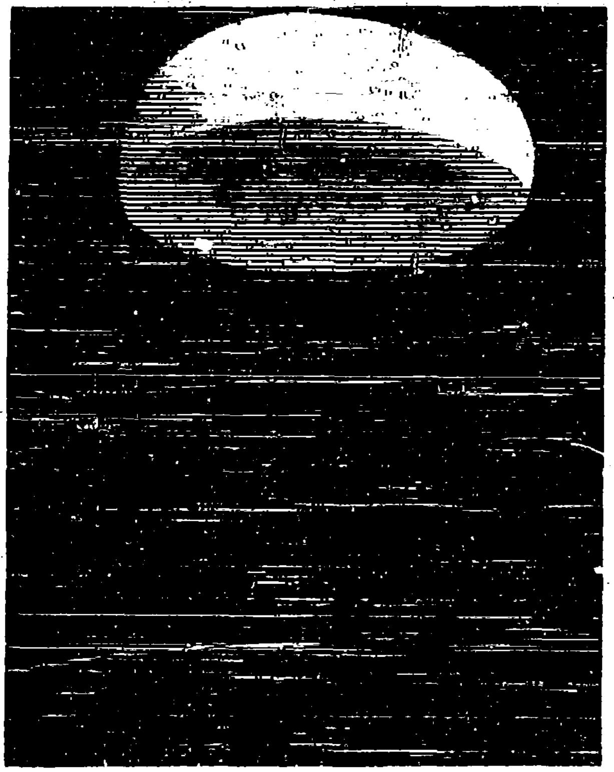


Figure 3-2-11. Experimental 200-ft. Diameter Parachute Canopy

prolonged reefing may be employed to achieve better accuracy of drop. In such cases, stage reefing may be desirable. In a majority of cases where reefing is presently employed, a 2-second reefing time will serve the purpose. An increase in reefing time automatically raises the minimum altitude at which the drop may be accomplished successfully. Reefing system design and fabrication must be simple to permit local installation.

2.8 SKIRT HESITATOR.

Skirt hesitators are often employed on aerial delivery parachute canopies to prevent inflation before line stretch is complete. This is particularly desirable in cases where snatch force would exceed the opening shock.

2.9 DEPLOYMENT METHODS.

2.9.1 GENERAL. Deployment of aerial delivery parachute canopies may be by pilot chute or by static line. Complicated deployment systems are not desirable, since they increase cost, maintenance, and rigging time.

2.9.1.1 A very satisfactory system has been devised for forced ejection of an extraction parachute by means of a spring-loaded tray or similar device. This method of forced ejection makes it possible to eliminate the pilot chute. The tray, essentially a catapult, may be mounted on the floor, side wall, or ceiling of the cargo compartment of the aircraft (see Figure 3-2-21).

2.9.1.2 The simplest method which has been used successfully to initiate deployment of an extraction parachute is the pendulum method. In the present stage of development, a notched arm or pendulum bar and an S-1 bomb rack are mounted as a unit in the top aft portion of the cargo compartment (see Figure 3-2-22). The parachute is retained in a horizontal position by the bomb rack, engaging V-rings secured to the deployment bag. A short pendulum line runs horizontally from the deployment bag to

Figure 3-2-12. 100-ft. G-11A Parachute Canopy

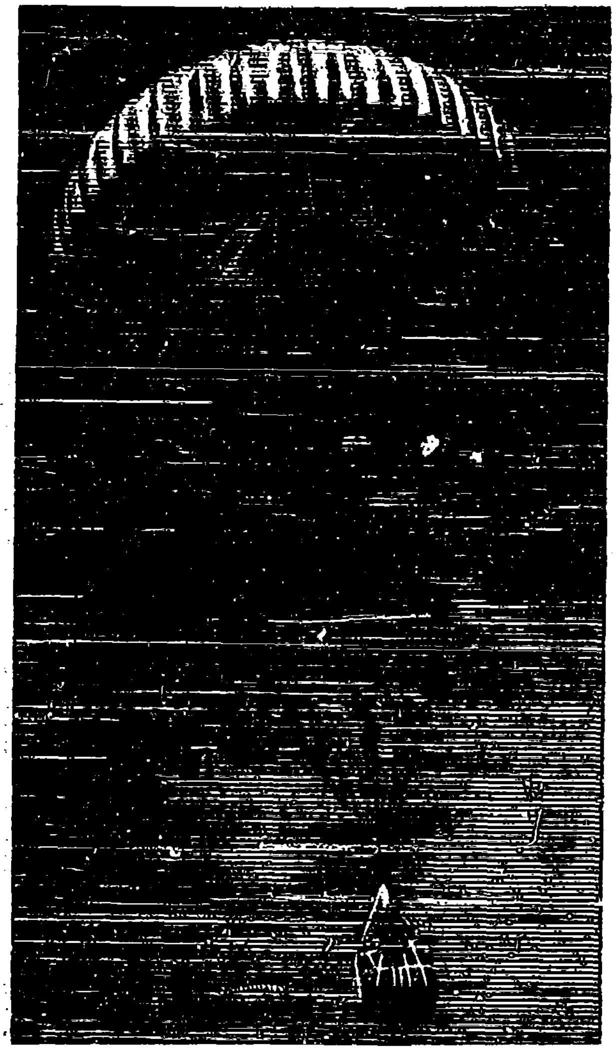


Figure 3-2-13. G-12 Parachute Canopy Lowering A-22 Container

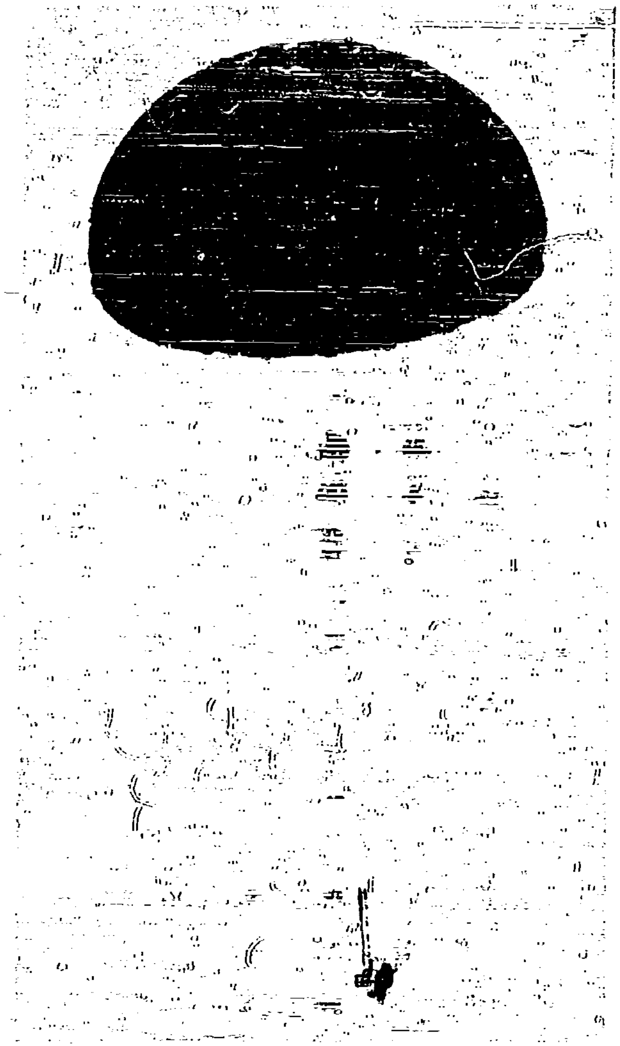


Figure 3-2-14. G-14 Hemispherical Parachute Canopy

the notch in the pendulum bar. Upon actuation of the bomb rack by either the pilot or alternate crew member, the parachute falls as a pendulum in an arc around the end of the pendulum bar until a satisfactory release attitude is reached, depending upon aircraft configuration. At this point, the loop in the pendulum line slips from the notch and the parachute is then free to be carried aft and subsequently deployed by the airstream.

2.9.2 DEPLOYMENT SYSTEM DESIGN. The deployment system must be kept as simple as possible. Small loads generally can be thrown or dropped from the aircraft by utilizing a simple static line to open the parachute.

2.9.2.1 Cargo canopies for 100- to 500-lb. load capacity are packed in the standard type envelope pack. This pack is attached to the load and does not assist deployment. The static line is attached directly to the apex of the canopy. Reliability is not as good as that of many other systems, but cost and simplicity warrant extensive use of this system. The G-13 and the T-7 (as converted for cargo) parachutes are most often used with this system.

2.9.2.2 For cargo loads between 1,500 and 2,200 lb. utilizing an A-22 container and a G-12 parachute (Figure 3-2-13), a nylon deployment bag is used. Deployment is initiated by a 68-inch octagonal pilot chute, which is

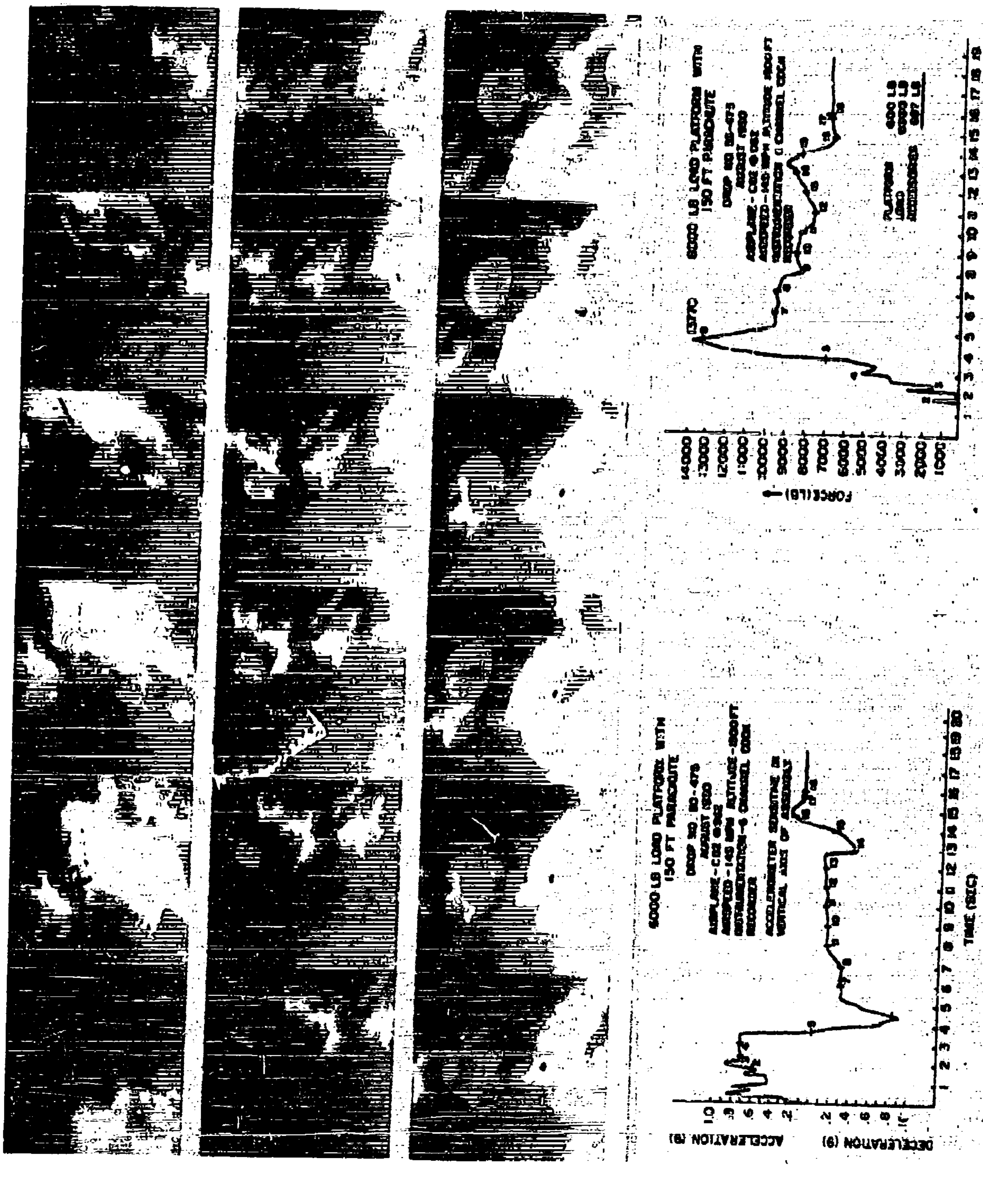


Figure 3-2-15. Deployment and Opening of a 150-Foot Aerial Delivery Canopy

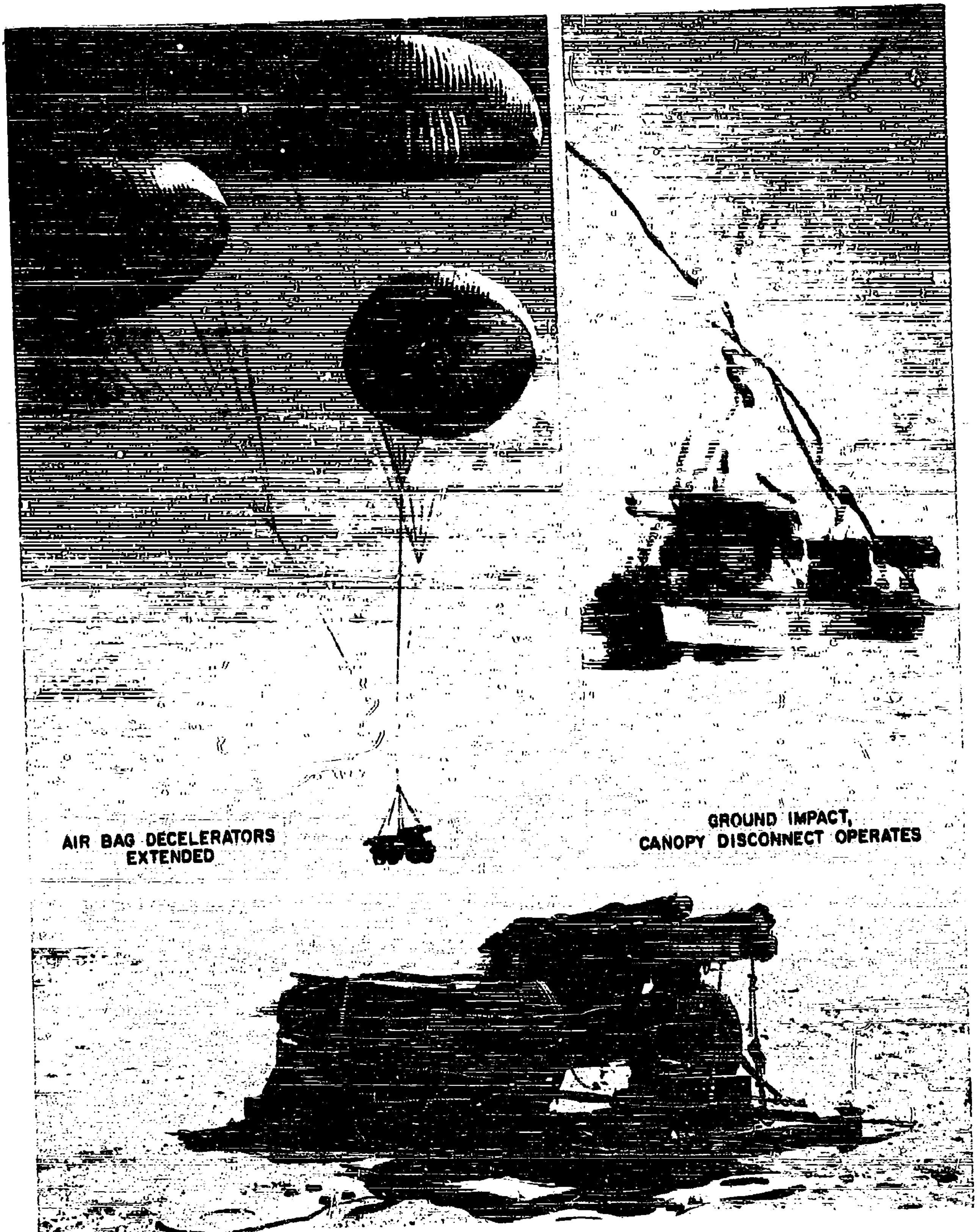


Figure 3-2-16. 105-Millimeter Howitzer Drop Using Stressed Metal Type Platform

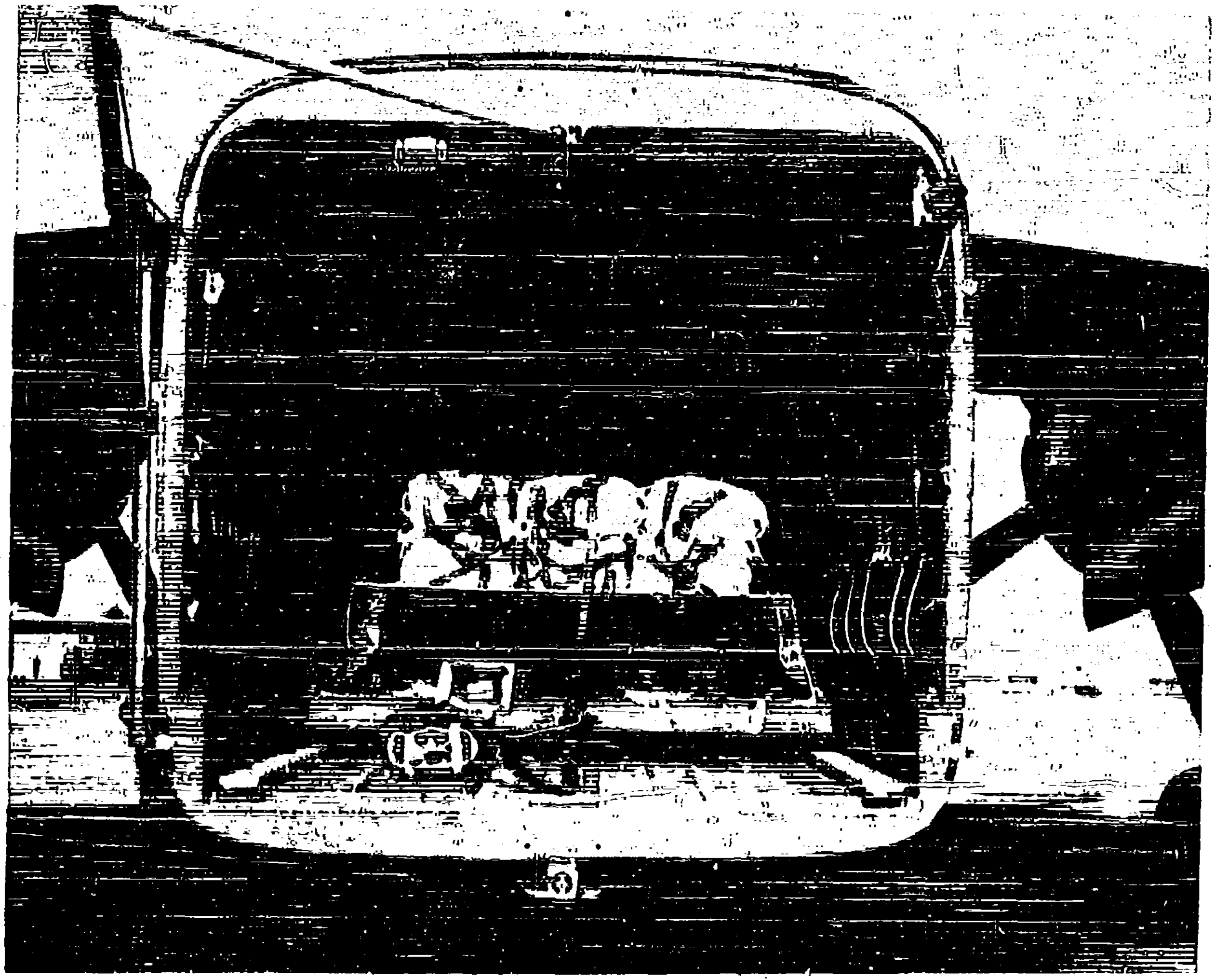


Figure 3-2-17. Stressed Metal Type Platform — Center Rail Restraint

deployed by static line attached to the aircraft.

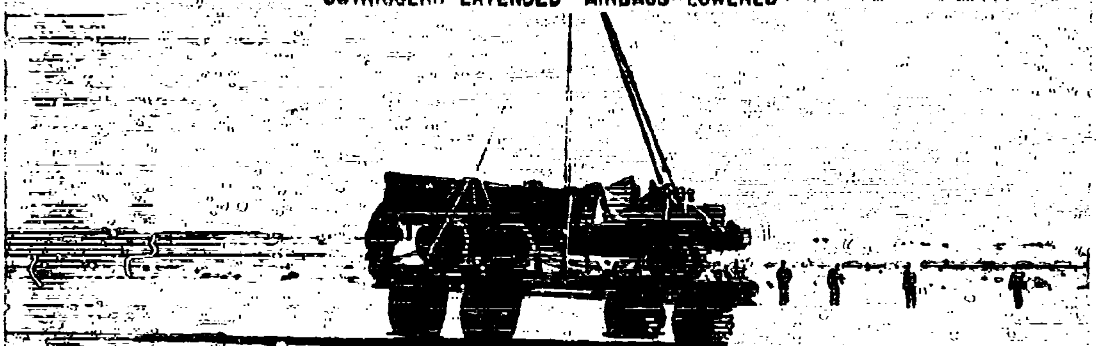
2.9.2.3 Cotton duck deployment bags are used for the G-11A parachutes.

2.10 CANOPY GROUND REL ASE SYSTEM.

Unless the parachute canopy is released immediately upon ground impact of the load, surface wind may cause the canopy to drag, topple, or otherwise damage the cargo. Figure 3-2-16 shows the release of the canopy system by electrical squib just as the ground contact takes place. Both mechanically and electrically operated release devices have been, and are being, developed for aerial delivery parachute systems. A description of these devices may be found in Chapter VI.

Figure 3-2-18. Center Rail Restrained Stressed Metal Type Platform with Air Bags and Anti-toppling Devices — 100-Ft. Diameter G-11A Parachute Canopies Are Used

OUTRIGGERS EXTENDED - AIRBAGS LOWERED



INSTANT OF AIRBAG GROUND IMPACT

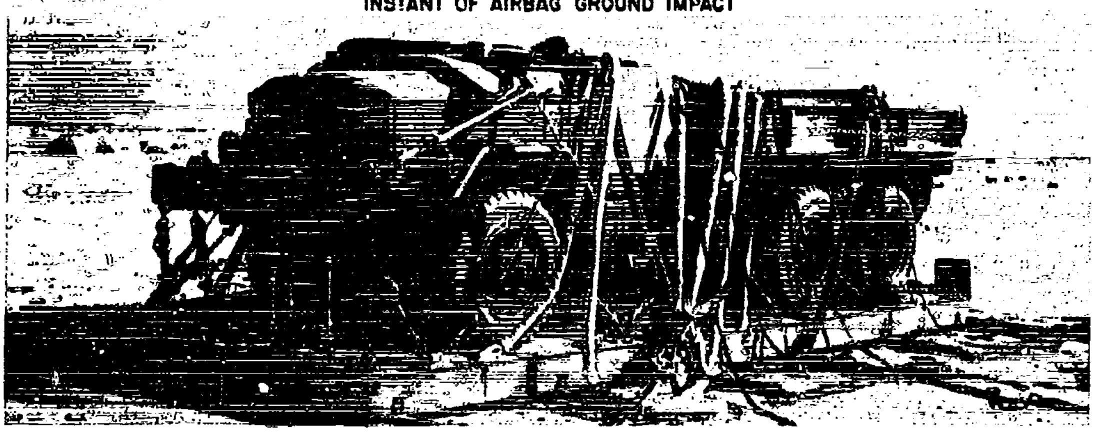


Figure 3-2-19. 2 1/2-Ton Truck Lowered with Stressed Metal Type Platform

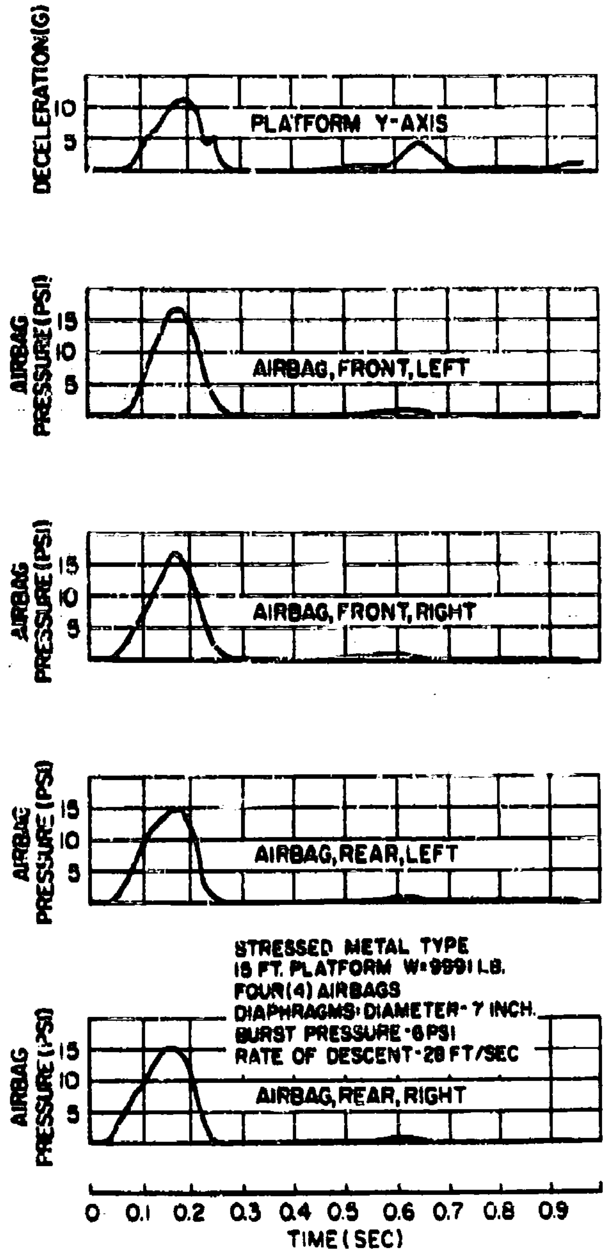


Figure 3-2-20. Deceleration and Air Bag Pressure Versus Time Histories Obtained During Ground Impact of a Stressed Metal Type Platform

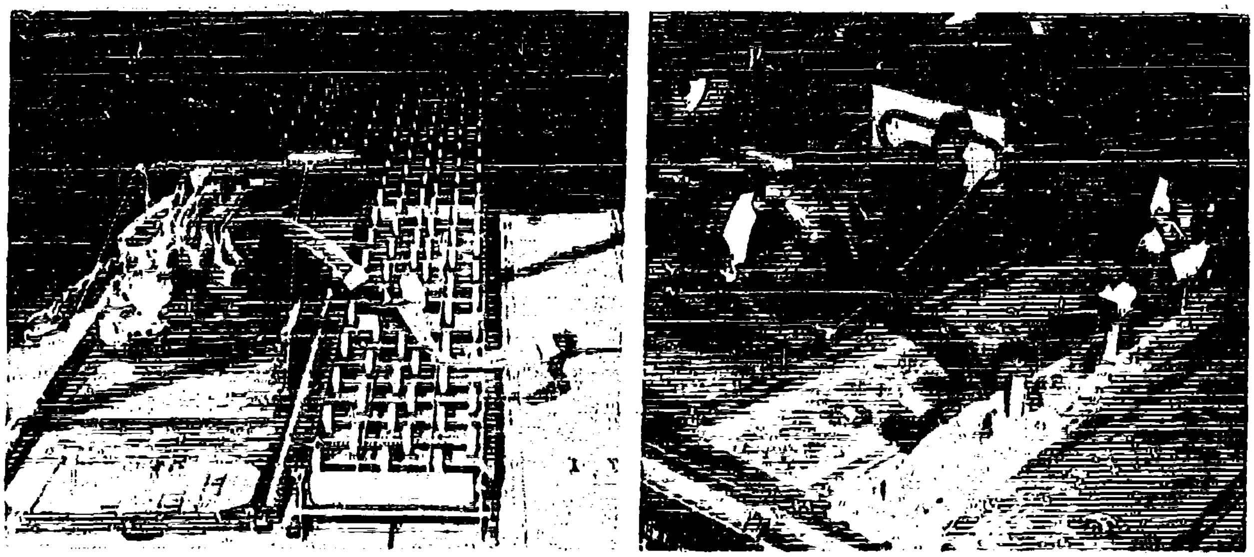


Figure 3-2-21. Spring-Loaded Tray for Extraction Parachute Ejection. The Position of the Tray Serving as a Back Wall Snaps Forward and Flat After Parachute Ejection. The Tray on the Left is Used with a Conventional Roller Conveyor System. The Tray on the Right is Used with a Center Rail Restraint System

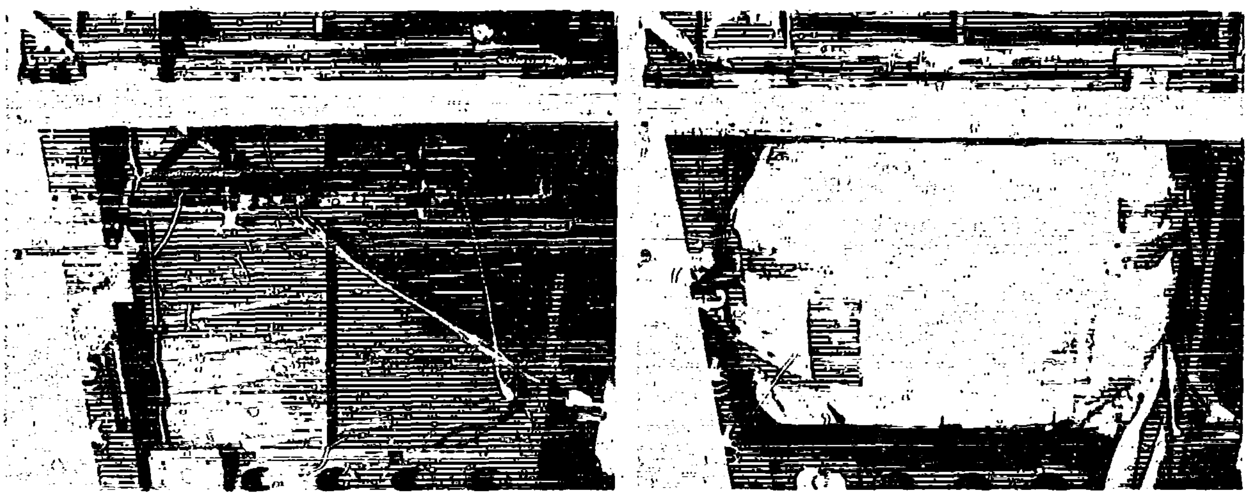


Figure 3-2-22. Pendulum System for Extraction Parachute Deployment

CHAPTER III

SECTION 3

STABILIZATION

3.1 GENERAL.

Parachutes offer certain definite advantages for stabilizing free-falling bodies. They provide a relatively large stabilizing force at a considerable distance from the center of gravity of the object to be stabilized without exacting an undue premium in weight or bulk. They have a particular advantage over fin-type stabilized objects, which are carried externally on an aircraft, in that they do not contribute to the object's drag until after the drag can no longer affect the aircraft's performance.

3.2 FUEL TANK PARACHUTE STABILIZATION.

3.2.1 CONSIDERATIONS. The use of external droppable tanks on high-performance aircraft necessitates investigation of tank aerodynamic characteristics. The trend of modern droppable fuel tank design is toward an elongated cylinder with fore and aft streamlining. When mounted on the wingtip, its angle of incidence is generally the same as that of the wing. When mounted inboard and under the wing, it is generally hung from streamlined supports in a manner that produces about zero degrees angle of attack at the normal cruising speed of the aircraft. It has been found advisable to stabilize tanks mounted inboard of the wingtip. Any slight positive angle of attack tends to pitch up the nose of the tank upon release. On full tanks, the weight involved overrides the aerodynamic lift and the tanks drop free and clear; on empty or near-empty tanks, pitching of the tank can endanger the aircraft structure. It is possible to devise fins that will stabilize the tank, but the additional drag caused by the fins will be high. Stabilization by parachute has proven satisfactory, and the bulk and weight of the system is relatively small.

3.2.2 FUEL TANK PARACHUTE STABILIZATION SYSTEM REQUIREMENTS.

a. Immediate stability upon release of fuel tank.
b. Minimum bulk to decrease fuel capacity penalty.
c. Reliable deployment system.
d. Sufficient drag to insure release of the tank.
e. Low opening shock or a suitable mechanical arrangement to insure that the tank will not be released before the parachute canopy is open and capable of producing the required stabilization.
f. A provision to drop full tanks (such as at takeoff) without the parachute canopy imposing a considerable load on the aircraft for an appreciable time interval.

3.2.3 FUEL TANK PARACHUTE STABILIZATION SYSTEM DESIGN. Fuel tank parachute stabilization systems generally use a portion of the rear cone of the drop tank as a pilot chute. See Figure 3-3-1. As the forces on the rear cone may be negative, the cone must be spring-loaded for positive ejection. The tail cone section then pulls out the main canopy. The present fuel tank parachute stabilization system used on the B-47 aircraft utilizes an 8-foot FIST ribbon chute reefed down to 7 1/2 feet in diameter See Figure 3-2-2. It is contemplated that ring slot parachutes will generally be used in future installations.

3.3 BOMB PARACHUTE STABILIZATION.

3.3.1 GENERAL. The use of parachutes for bomb, mine, or torpedo stabilization permits stowage of a greater payload within a compartment than would be possible if the bombs were fitted with fixed fins capable of producing the same stabilizing effect.

3.3.2 BOMB PARACHUTE STABILIZATION SYSTEM REQUIREMENTS.

a. Rapid stabilization upon deployment of the parachute canopy.
b. Constant or predictable drag coefficient for accurate computation of flight path.

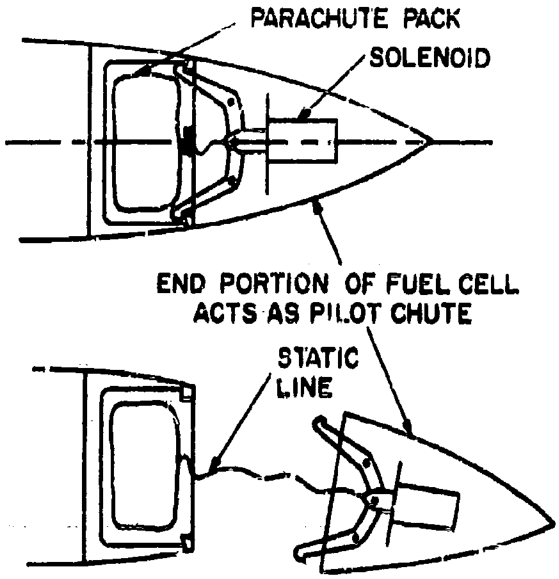


Figure 3-3-1. Droppable Fuel Tank Parachute Stabilization System

c. Ability to withstand opening shock without damaging distortion at highest altitude and airspeed anticipated for drop.
d. Stability at highest velocity of ±2 degrees.

3.3.3 BOMB PARACHUTE STABILIZATION SYSTEM DESIGN. Bomb parachute stabilization systems usually employ ribless or ribbed guide surface parachutes. To decrease oscillation, the forces on the canopy are transmitted directly to the body of the bomb by means of a geodetic suspension system (see Figure 3-3-3). The distance between the bomb and the parachute skirt varies between 3.5 and 4.0 times the diameter of the bomb at its widest portion (generally at the designed cg). The shorter distance is preferable for rigidity of the suspension system, but the wake effect of some bombs makes the longer distance necessary. Deployment of the parachute is accomplished by static line. Since bomb accuracy is adversely affected by decrease in speed, it is desirable to use the smallest parachute that will achieve the required degree of stabilization. When a properly designed adapter housing is used, the parachute system adds very little to the overall bomb length. The system shown in Figure 3-3-4 achieved a decrease in bomb length over the standard fin assembly bomb of better than 20 percent and weight savings of about 20 pounds.

3.4 DROPPABLE WHEEL PARACHUTE RECOVERY.

3.4.1 GENERAL. Installation of extra long range fuel tanks or heavier than normal armament may bring the takeoff weight of an aircraft above the designed wheel loading of the aircraft. It is therefore desirable to supplement the normal landing gear with additional wheels and tires (see Figure 3-3-5). This can be accomplished by the use of auxiliary wheels, which assume a portion of the load during takeoff. Immediately after takeoff, such wheels must be dropped because of lack of provision for carrying them in the retracted position and also because they will not be necessary once the fuel or armament is expended. Such wheels also can permit takeoffs from semiprepared or light duty runways. Recovery of the wheels may be accomplished by a small parachute. The parachute serves to rapidly decrease the speed and distance the wheels travel after drop.

3.4.2 REQUIREMENTS FOR A DROPPABLE WHEEL PARACHUTE RECOVERY SYSTEM.

a. Rapid-opening canopy.
b. Simple one-parachute system.
c. Positive deployment system.
d. Provision on the auxiliary wheel for housing the parachute.

3.4.3 DROPPABLE WHEEL PARACHUTE RECOVERY SYSTEM DESIGN. In this system, the degree of stabilization is not of primary concern. The octagonal canopy shown in Figure 3-3-5 has proved quite adequate. Accelerated

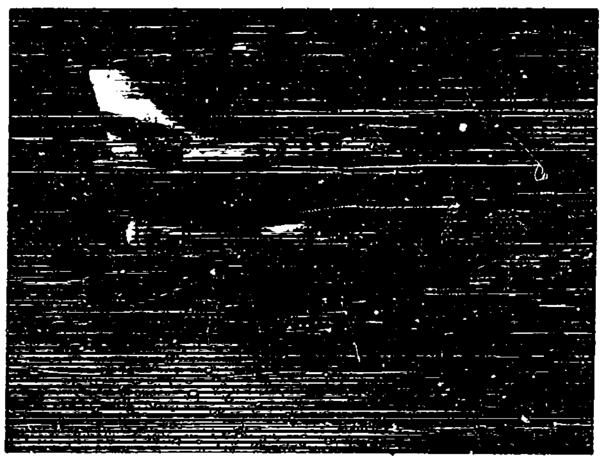
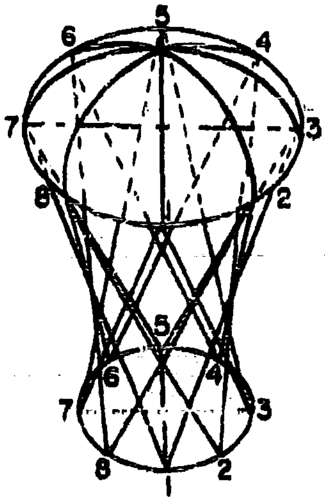
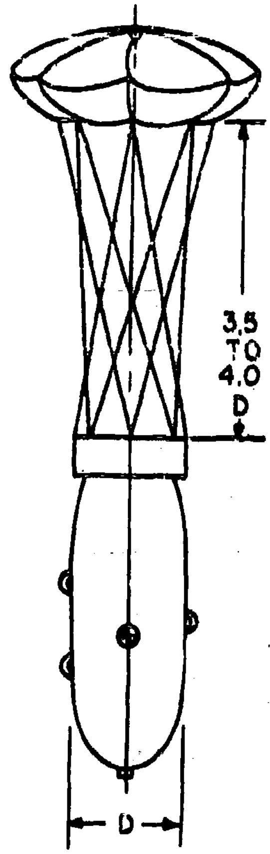


Figure 3-3-2. Parachute Stabilized Fuel Tank Dropped from a B-47 Aircraft



CONNECT POINT	TO POINTS
1	7,3
2	8,4
3	1,5
4	2,6
5	3,7
6	4,8
7	5,1
8	6,2
ON SKIRT	ON BOTTOM



8 PANEL PARACHUTE

SUSPENSION LINE ADJUSTMENT IS ACHIEVED BY PLACING ONE DISC IN THE MOUTH OF THE PARACHUTE (SIMULATING THE INFLATED PARACHUTE) AND A SECOND DISC AT THE FREE END OF THE SUSPENSION LINES. THE LOWER DISC MUST BE WEIGHTED AND THE TWO DISCS MUST BE PARALLEL.

Figure 3-3-3. Geodetic Suspension System

opening should be strived for, and may be achieved by canopy selection and use of pocket bands. Deployment should be accomplished by use of a simple static line system from the strut to the droppable wheel that is designed to break at the strut.

3.5 EJECTION SEAT AND EMERGENCY ESCAPE CAPSULE PARACHUTE STABILIZATION.

3.5.1 GENERAL. Seat ejection at high subsonic and supersonic speeds poses a stabilization problem. Aerodynamic forces can cause such abrupt and rapid tumbling of the seat that physical and mental control may be lost. Many avenues of research are being taken to overcome this problem, including aerodynamically stabilized capsules or compartments, parachute stabilized capsules or compartments, and parachute stabilized ejection seats.

3.5.2 REQUIREMENTS FOR EJECTION SEAT AND EMERGENCY ESCAPE CAPSULE STABILIZATION BY PARACHUTE.

a. Extremely rapid deployment of stabilization parachute to avoid canopy fouling on gyrating seat or capsule.
b. Rapid and reliable opening at subsonic and supersonic airspeeds.
c. Positive parachute deployment; forced ejection to deploy parachute in an area not affected by the wake of the seat or capsule.
d. Sufficient drag to check seat or capsule tumbling before parachute system is fouled.
e. Manual control must be possible for any individual operation during the sequence prior to the deployment of the recovery parachute. If manual control is not used, automatic control must take over.

3.5.3 EJECTION SEAT AND EMERGENCY ESCAPE CAPSULE PARACHUTE STABILIZATION SYSTEM DESIGN. Because deployment may take place at supersonic airspeeds, and very rapid parachute canopy opening characteristics are required, the canopy selected must be able to withstand high opening shock. However, the opening shock of the canopy shall not exceed human tolerances. Gravitational forces imposed upon the seat or capsule by the parachute canopy shall not exceed 20 g for a period of one second, and force rate of onset shall not exceed 200 g per second. Canopy deployment must be rapid and positive, and must be accomplished in an area not blanketed by the seat or capsule. Normally, positive deployment requires forceful ejection of the parachute by means of ejector guns, blast bags, or other pyrotechnic systems. The bridle must be designed for quick stabilization of the seat or capsule without creating excessive snap or overcorrection. Present designs consider the use of a ribless guide surface type parachute, which is automatically deployed by means of ejection gun or other devices, to stabilize the seat or capsule. Recovery parachutes for final descent are based on cargo type or missile recovery parachute designs. Projected ejection seat designs allow for altitude controlled separation of person and seat, while on others, the person remains in the seat all the way to the surface. On the latter type, a main recovery parachute must be packed and carried on the seat. Stabilization parachute canopy designs are basically identical to those used for first stage missile and drone recoveries. A schematic diagram of possible stabilization parachute system operation for a pilot ejection seat is shown in Figure 3-3-6.

Figure 3-3-4. Parachute Stabilization System on 2,000-Pound GP Bomb

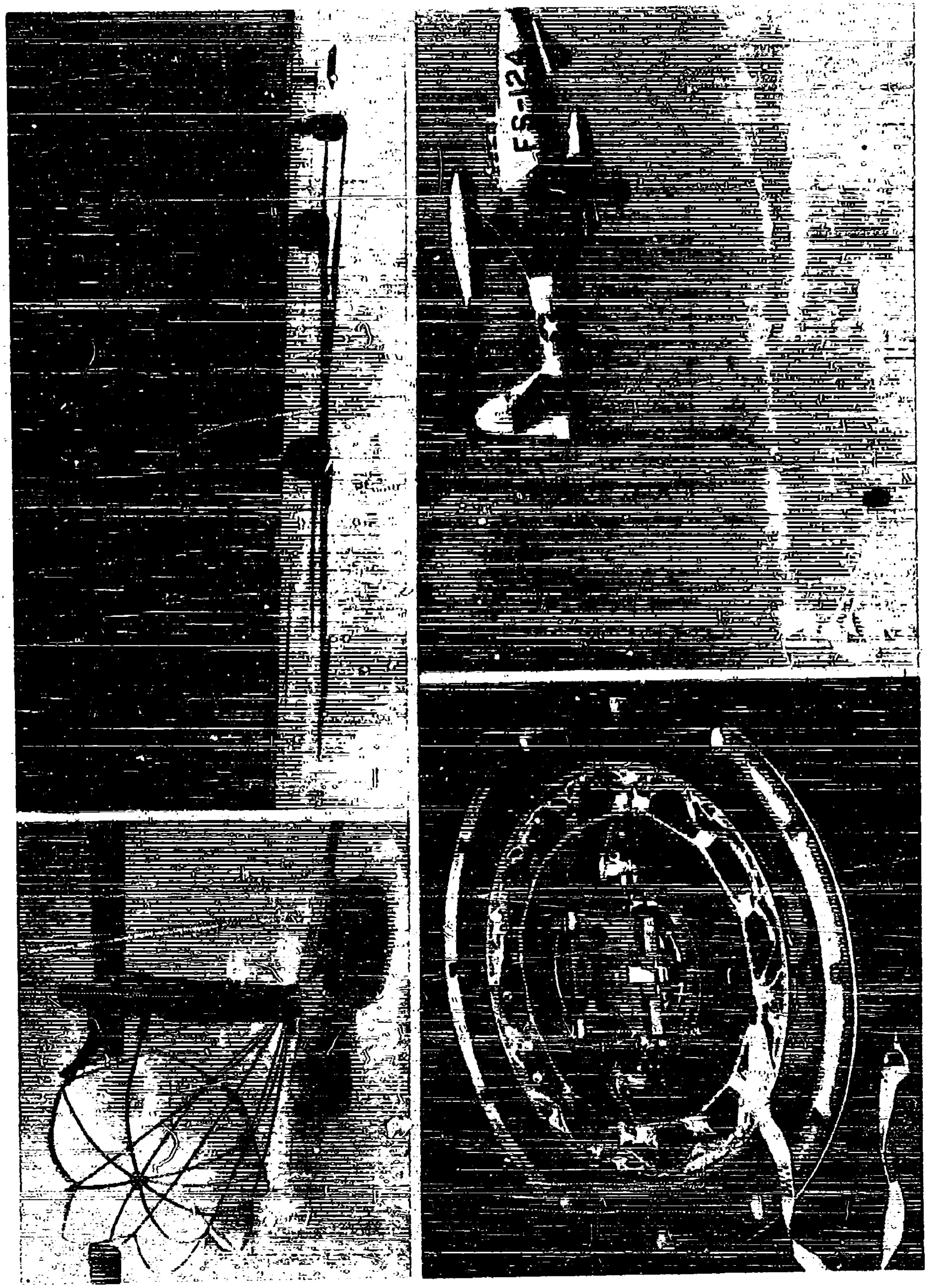


Figure 3-3-5. F-84G Aircraft with Droppable Wheels, and Droppable Wheel Recovery System

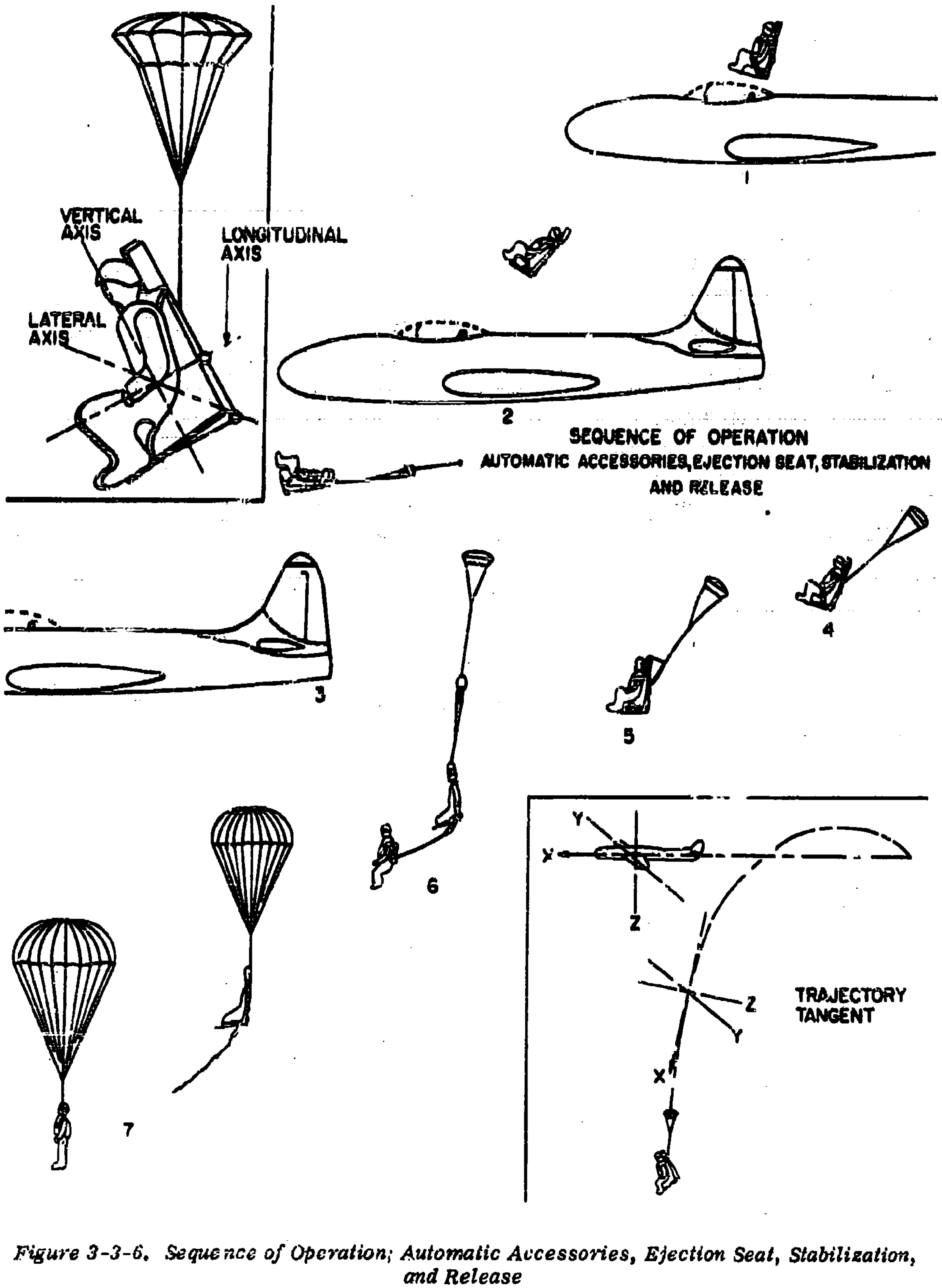


Figure 3-3-6. Sequence of Operation; Automatic Accessories, Ejection Seat, Stabilization, and Release

(For 400 Lb./Sq. Ft. Impact Pressure)

TYPE	Projected Diameter Ft	Projected Area Sq Ft	Drag Coefficient c_D	Opening Time Sec	Opening Shock Factor	Ratio of Max. Diam. to Design Diam. %	Stability Angular Displacement Mean Degree	Stability Angular Displacement Max. Degree
GUIDE SURFACE, RIBLESS	6.5	33.2	0.79	0.11	1.38	92.6	1.39	1.94
GUIDE SURFACE, STABILIZATION	6.5	33.2	0.97	0.21	1.03	102.3	1.62	2.83

TYPE	Nominal Diameter Ft	Canopy Area Sq Ft	Total Porosity %	Drag Coefficient c_{D_o}	Opening Time Sec	Opening Shock Factor	Ratio of Max. Diam. to Design Diam. %	Stability Angular Displacement Mean Degree	Stability Angular Displacement Max. Degree
FIST RIBBON	8.6	56.6	17.6	0.55	0.21	0.84	105.7	2.32	3.84

TYPE	Nominal Diameter Ft	Canopy Area Sq Ft	Total Porosity %	Drag Coefficient c_{D_o}	Opening Time Sec	Opening Shock Factor	Ratio of Max. Diam. to Design Diam. %	Stability Angular Displacement Mean Degree	Stability Angular Displacement Max. Degree
RING SLOT (4 SLOTS)	7.72	46.8	23.5	0.55	0.18	0.95	117.5	5.2	6.7

TYPE	Nominal Diameter Ft	Canopy Area Sq Ft	Geometric Porosity %	Drag Coefficient c_{D_o}	Opening Time Sec	Opening Shock Factor	Ratio of Max. Diam. to Design Diam. %	Stability Angular Displacement Mean Degree	Stability Angular Displacement Max. Degree
ROTOFOIL EX 7-8	7.0	34.6	23.1	0.78	0.40	0.86	95.1	4.62	9.18

Figure 3-3-7. Parachute Canopy Characteristics

CHAPTER III

SECTION 4

GUIDED MISSILE AND DRONE RECOVERY

4.1 GENERAL.

In practically every case, the recovery system for a guided missile or drone must be individually tailored to the particular missile or drone. The problem of providing a suitable recovery system for a particular missile or drone can be broken down into three steps: (1) overall design of the recovery system, (2) detailed design of the individual stages and components, and (3) fabrication and testing of the resulting hardware. The development and testing of parachutes for applications other than human escape from aircraft has been sponsored largely by the military services. Theoretical considerations and design criteria in this field are sufficiently fluid to permit the introduction of new ideas, designs, and procedures, provided they are proven by test. It is recommended that recovery system designers maintain close liaison with governmental agencies that are responsible for design development of parachutes, in order to profit from the latest experience in this field.

4.2 OVERALL DESIGN.

4.2.1 PRINCIPLES. The basic precept for designing any recovery system is to decelerate and lower the recoverable body from the speed and altitude at which it is traveling prior to recovery to a low vertical speed at which ground impact shall cause a minimum of damage.

The designer must study the recovery system and devise a system complete with number of stages, parachute types and sizes, parachute compartment location and configuration, deployment system and procedure, release and control system, and landing shock-absorbing or flotation, as applicable to the type of body to be recovered.

Before any one stage or component of a recovery system can be designed, it is necessary for the designer to give consideration to the overall requirements and conditions imposed by the missile design.

The final design of a parachute recovery system must reflect the best possible compromise between size of parachute, cost, damage factor, and decrease in performance of the missile caused by weight and bulk of the recovery system.

The operational sequence for a multiple-stage parachute recovery system is graphically shown in Figure 3-4-1.

Possible approaches to recovery systems are presented in Figures 3-4-2 and 3-4-3. The system shown in Figure 3-4-2 consists of a three-stage parachute recovery. Parachutes are deployed rearward along a line parallel to the flight path of the missile. The drag parachute is deployed by means of forced ejection. After a predetermined deceleration period, the drag parachute takes over the function of an extraction parachute, deploying the main recovery canopy. The main canopy, which is initially reefed, will inflate fully after a preselected time interval. The landing spike has the purpose of absorbing ground impact shock upon landing. The system shown in Figure 3-4-3 approaches the recovery problem differently. In this case, the missile, which is not equipped with a landing spike, has to be lowered in a horizontal attitude in an upside-down position, however, to prevent damage to the power plant. A drag parachute, deployed rearward, decelerates the missile sufficiently for safe deployment of the main canopy. Deployment of the main canopy can be accomplished either by utilizing the drag parachute for the extraction purpose, or by using a separate extraction parachute canopy. The missile is turned over during the period of main canopy inflation. Landing shock-absorbing devices are deployed at the same time.

The trajectories, which are provided in Figure 3-4-4, are calculated for bodies having zero lift, and are dropped horizontally with the initial velocity v_0. The effect of the drage area of a body having the weight W (including parachute(s)) results in an equilibrium velocity v_e at an altitude with the density ρ. The

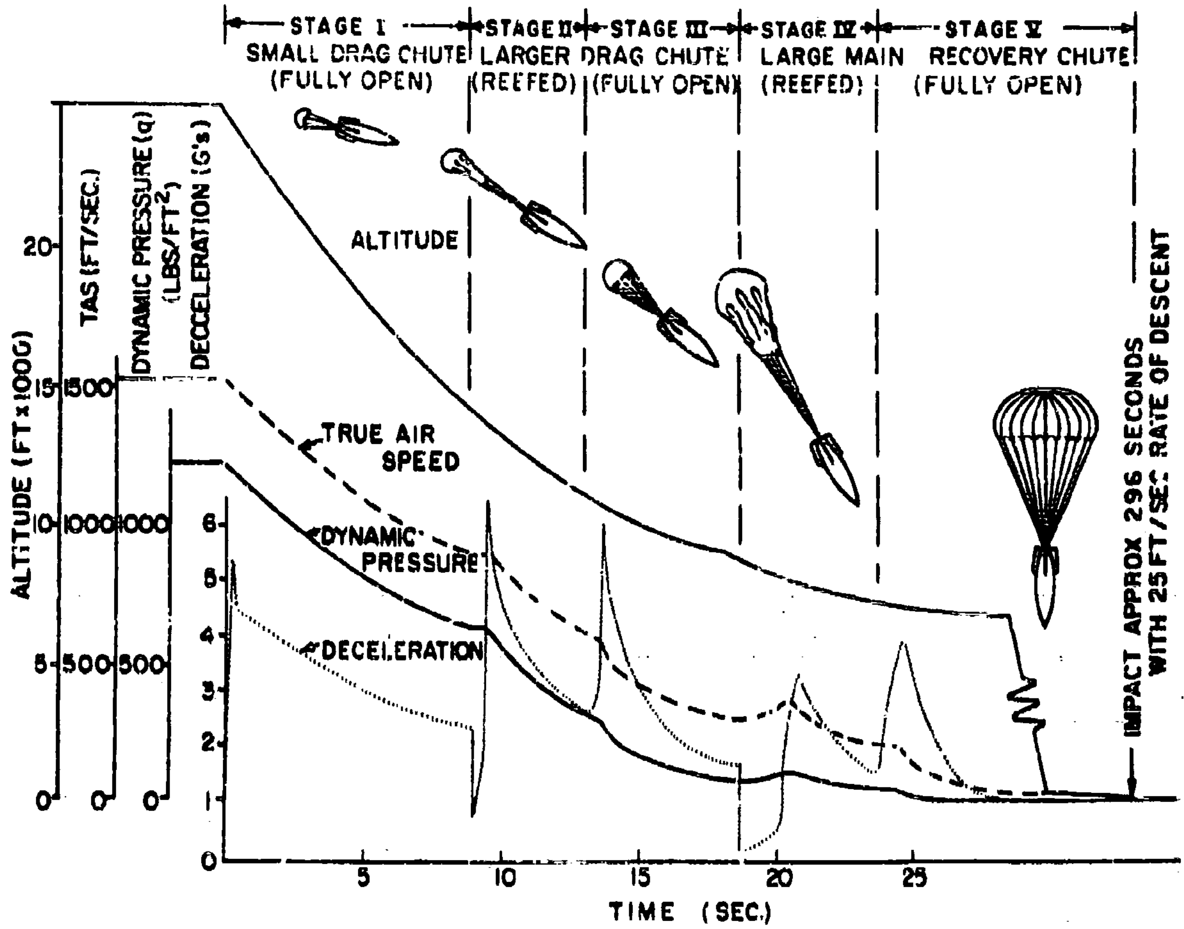


Figure 3-4-1. Possible Operational Sequence for a Multiple Stage Parachute Recovery System

velocity decay versus time is indicated in dimensionless form, whereby the initial or release velocity is 1.0 at the time zero. The equilibrium velocity, vertical distance, and trajectory angle are plotted as families of curves. This graph can be utilized for bodies where the lift or thrust are close to zero or relatively small in comparison to the drag.

As an aid for the calculation or determination of body deceleration, parachute forces, and other parameters, charts showing the deceleration of bodies with a straight line flight path, incompressible dynamic pressure as a function of Mach Number and altitude, and ratio of compressible to incompressible dynamic pressure versus Mach Numer are presented as Figures 3-4-5 and 3-4-6. For the calculation of curves showing the deceleration of bodies with a straight line flight path, the drag of the body proper is considered to be negligibly small in comparison to that of the parachute canopy. Curves have been plotted for a relase velocity v_o = 3000 ft./sec. for trajectory inclination angles of 0°, 30°, 60°, and 90°, and for a number of termical velocities v_e between 200 and 3000 ft./sec. It should generally be noted that altitude (and density) is kept out of the analysis by expressing the drag through the terminal velocity v_e (in a vertical drop).

4.2.2 INITIATION. Recovery is normally initiated by ground command; however, flight conditions such as engine failure, loss of control signal, or loss of braking signal also can be used to initiate recovery. In most cases combinations of these reasons are used to initiate recovery. The requirements of the particular missile or drone specification applies.

4.2.3 RECOVERY SEQUENCE. Recovery normally consists of, but is not limited to, two or more stages involving parachutes or other drag devices to accomplish the deceleration and

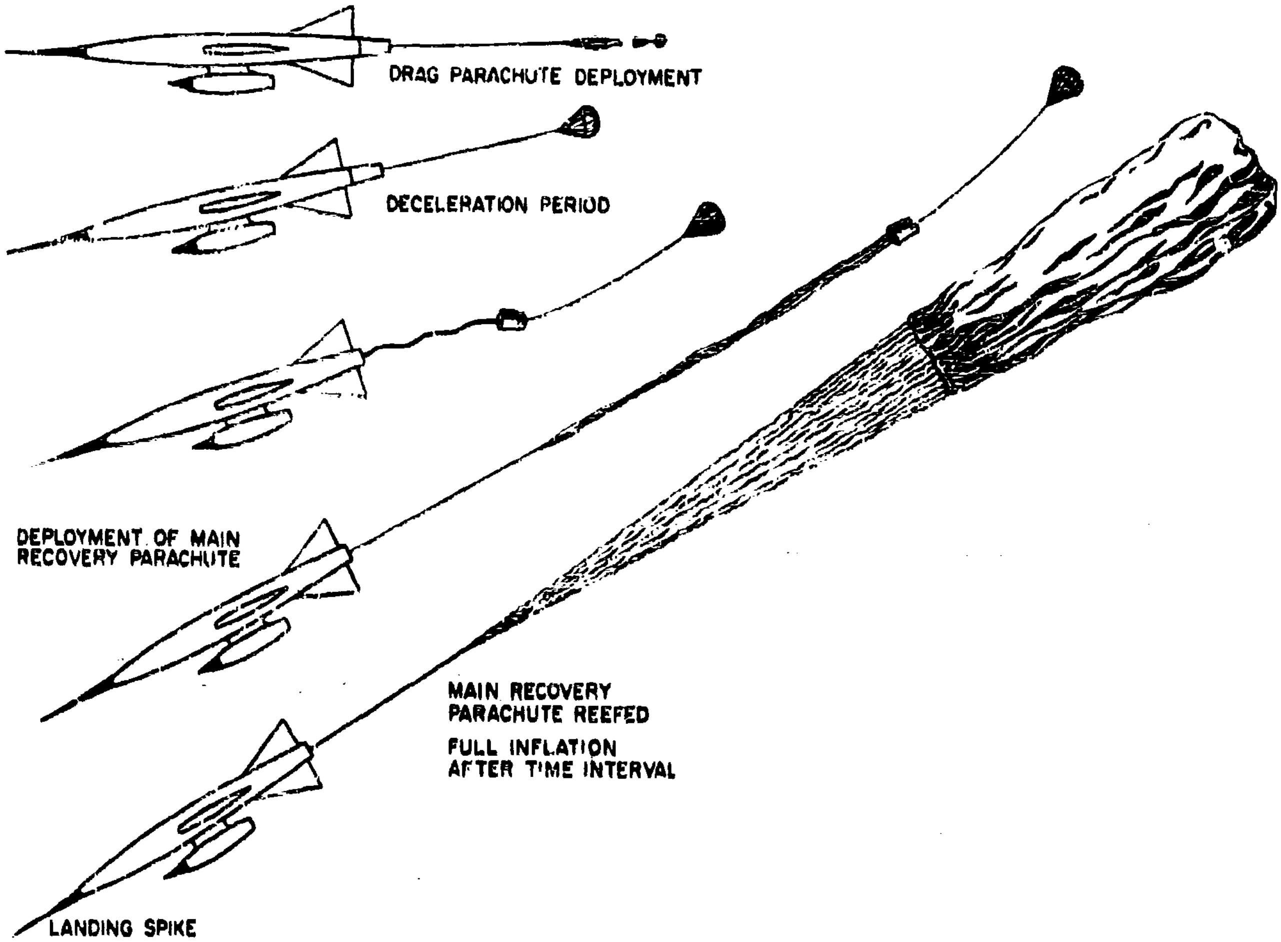


Figure 3-4-2. Functional Sequence, Parachute Recovery System I

subsequent descent to the ground. Figure 3-4-1 shows a plot of altitude and flight path speed for a typical five-stage recovery system. The number of stages and the design of the parachute for each stage is determined by the following recovery conditions:

a. Recovery speed and altitude. The requirements for the first-stage parachute design are determined by the speed and altitude at which it is to be deployed. The values selected shall be the most critical that can reasonably be expected during uncontrolled tests or operational flights of the missile or drone.
b. Recovery weight. The recovery weight is the weight of the missile, drone, or part thereof, to be recovered. This value can vary because of changing conditions or fuel load. Therefore, it should be the maximum weight under which recovery is to be made. Consideration must be given to reducing this value by dumping fuel or jettisoning parts of the recoverable body.

4.2.4 GENERAL DESIGN CONSIDERATIONS. Given here is a list of considerations necessary for missile or drone recovery system design.

4.2.4.1 Considerations for Missile and Drone Recovery System Design:

a. Possible range of speed at initial deployment.
b. Possible range of altitude at initial deployment.
c. Type of recovery desired, such as (1) rapid stabilized descent, (2) delayed descent, and (3) free descent in which final impact is the only consideration.

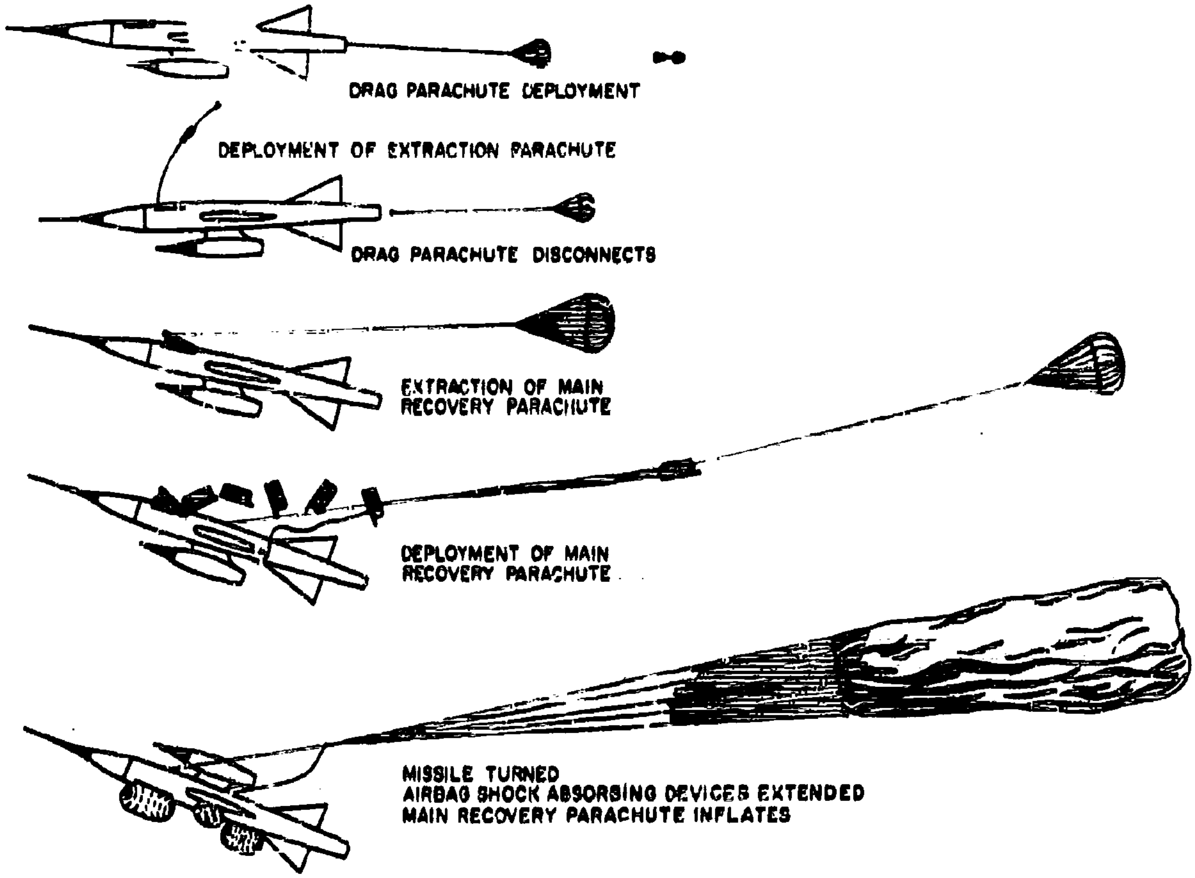


Figure 3-4-3. Functional Sequence, Parachute Recovery System II

d. Space available for parachute and impact reduction system.

e. Location of parachute(s), which may effect the insulation required and type(s) of deployment, such as (1) pilot chute(s), (2) static line(s), or (3) blast bag or other forced ejection equipment.

f. Bridle design, which takes in (1) desirable angle for missile support, (2) center of gravity of missile at time of deployment and descent, and (3) force limitations of vehicle at load connections.

g. Maximum g tolerances of vehicle and direction of g's.

h. Desirable stability and angle of descent at final impact.

i. Shock reduction system to be used for final impact.

j. Geographical or physiographical area in which vehicle is expected to operate.

k. Weight of vehicle at anticipated recovery time.

l. Position of first-stage chute at inflation, such as (1) motor blast effect — heat and pressure, and (2) wake effect.

4.2.4.2 Maximum Deceleration. This value is required to determine the number of stages required, the parachute sizes, and the timing of the recovery sequence. In the majority of cases, the deceleration forces developed at ground impact exceed the parachute-opening forces, unless special provisions are made to reduce these landing forces. Not only must the limit of the missile structure be considered in determining this value, but also the powerplant, the instruments, the control system, and other accessories.

4.2.4.3 Parachute Compartment Reliable recovery operations depend upon a minimum of interference with the parachute during the deployment procedure. The pack may be fabricated metal, but it must meet the requirements for packs mentioned in Chapter 2. There should be no projections or sharp edges in the way of

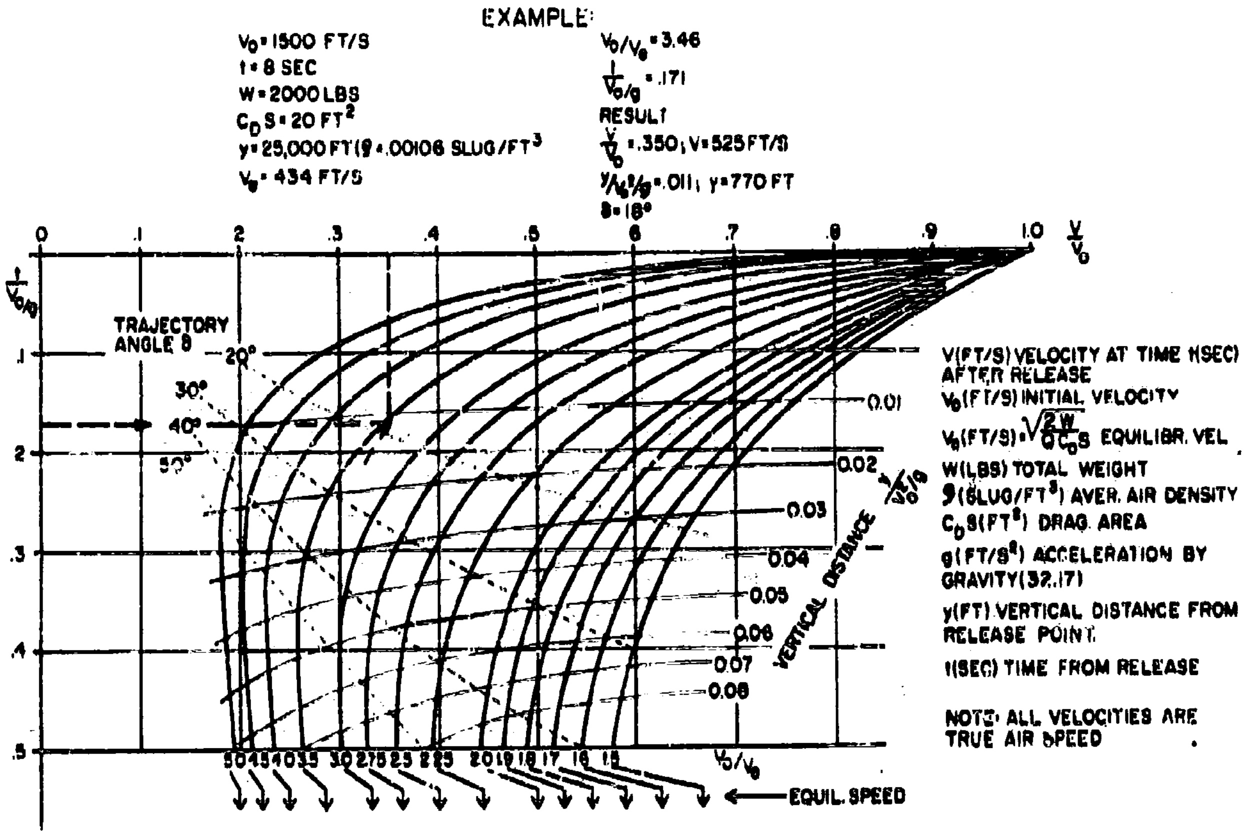


Figure 3-4-4. Ballistic Trajectories with Horizontal Initial Velocity

the deploying parachute. In general, the motion of the deploying parachute will be straight aft in relation to the flight path of the body. The best location for the parachute compartment is, therefore, in the extreme tail of the missile or drone. In many cases, however, the temperature of this location is excessive, because of its proximity to the power plant. In such cases, the possibility of insulating and/or cooling the compartment must be considered. If this is not practical, the compartment must be located in an area where excessive heat will not be encountered. However, the farther aft it is in the body, the better. It must be located so that the normal deployment path passes between such protrusions as tail surfaces. If possible, the aft wall of the compartment should have a considerable slope in order to aid in extracting the packed parachute. The outer edges of the compartment should be rounded, so that nothing can snag or tear the bag in which the parachute canopy is packed. In cases where the missile is normally expected to be in a tumbling condition at the time of deployment, the aft position will not necessarily be the best. The parachute compartment will then have to be designed for such special deployment method as is necessary.

4.2.4.4 Stability of Body Prior to Recovery. As previously mentioned, consideration must be given to the stability of the missile, drone, or portion thereof, just prior to the initiation of recovery. The recovery problem is greatly simplified in cases where control is exercised over the body up to the time the first parachute canopy is deployed. The recovery system, however, should be designed on the premise that this is not possible. Therefore, in order to provide reliable deployment, it is very important to know the approximate attitude of the recoverable body with respect to its flight path.

4.2.4.5 Deployment. This process must be orderly and, insofar as possible, there should be no slack in the connecting lines between the parachute canopy and the body being recovered. Consideration must be given to the deployment of the first-stage parachute or pilot chute by some forceful means, such as a mortar or gun, to ensure the reliability of

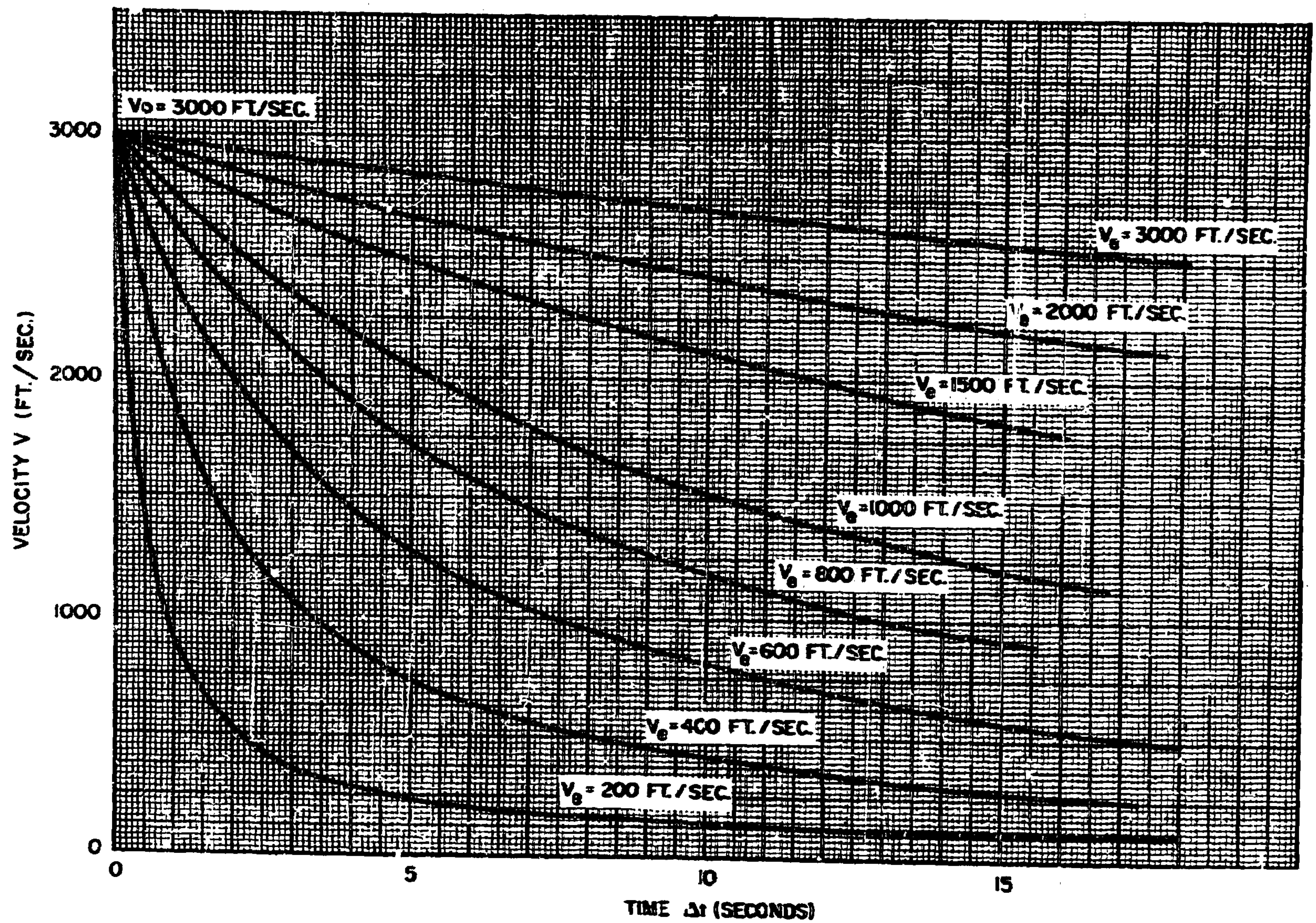


Figure 3-4-5. Deceleration of Bodies with Straight Line Flight Path (sheet 1 of 4)
(Trajectory Inclination Angle $\gamma = 0^0$)

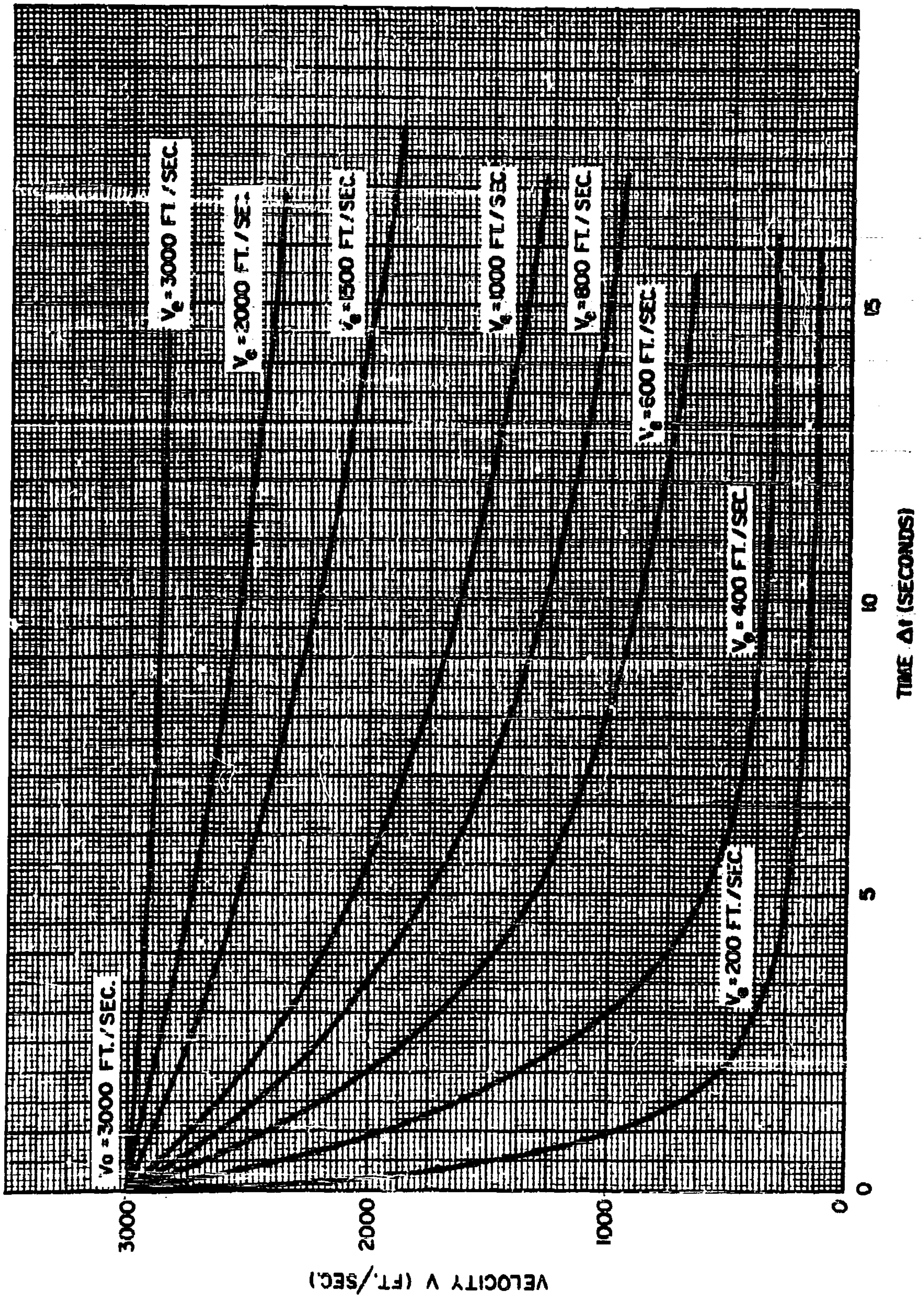


Figure 3-4-5. Deceleration of Bodies with Straight Line Flight Path (sheet 2 of 4)
(Trajectory Inclination Angle $\gamma = 30^o$)

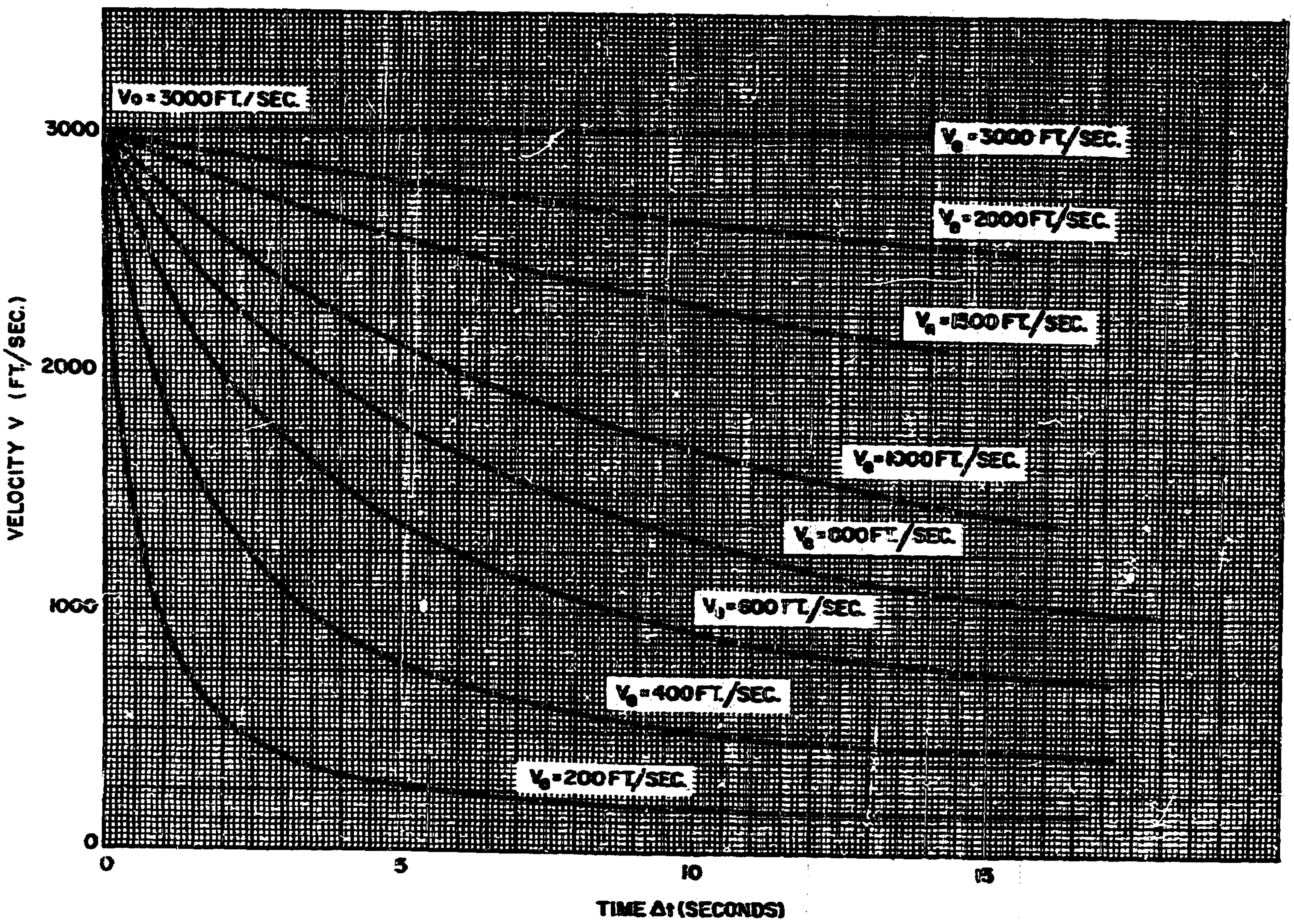


Figure 3-4-5. Deceleration of Bodies with Straight Line Flight Path (sheet 3 of 4)
(Trajectory Inclination Angle $\gamma = 60^0$)

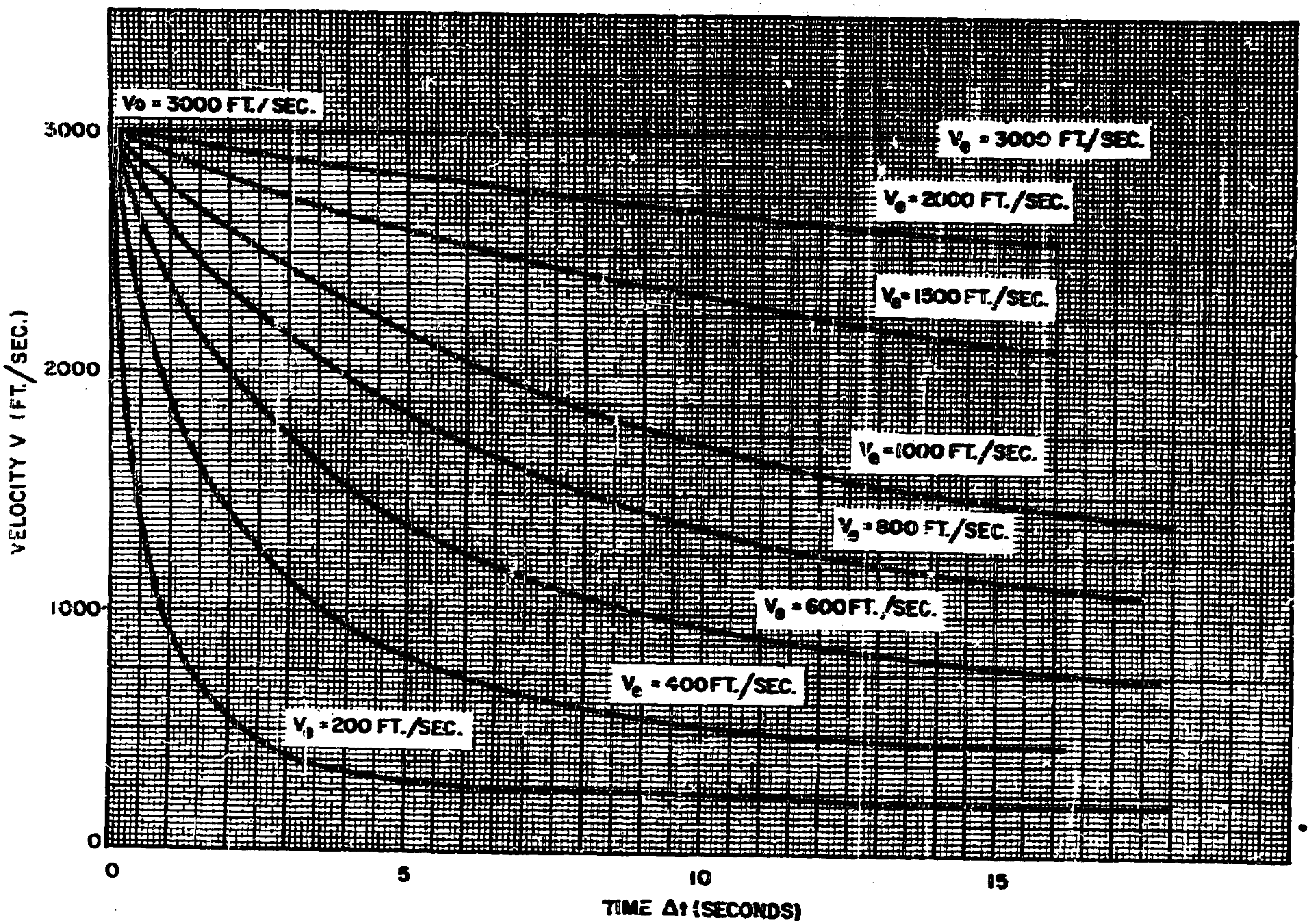


Figure 3-4-5. Deceleration of Bodies with Straight Line Flight Path (sheet 4 of 4)
(Trajectory Inclination Angle $\gamma = 90°$)

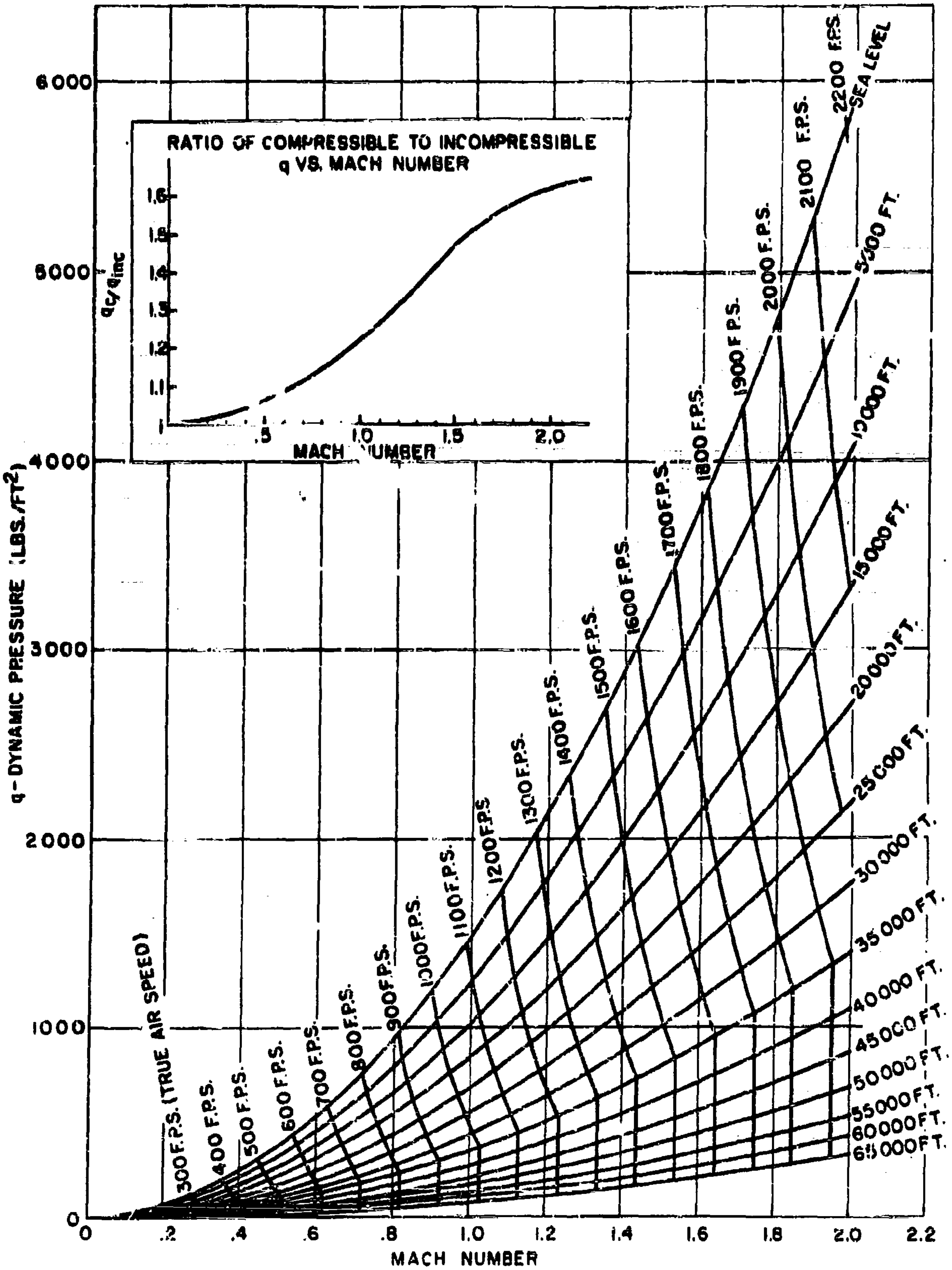


Figure 3-4-6. Incompressible Dynamic Pressure as a Function of Mach Number and Altitude

parachute action during this critical period. In addition, consideration must be given to possible detrimental effects on the deployed parachute from afterburners or rocket heat. Provision must be made to minimize or eliminate this condition.

A parachute deployment sequence for first stage or second stage application is schematically shown in Figure 3-4-7. In this system, both a gun-ejected pilot parachute and a blast bag aid the orderly deployment of the parachute. The use of a pilot parachute is considered mandatory for the deployment sequence. It tends to keep the deploying system along a line parallel to the flight path, assures orderly deployment, and eliminates excessive parachute canopy snatch and opening forces.

4.2.4.6 Forced Ejection. In cases where parachutes have to be deployed along a trajectory vertical to the flight path of the missile, the necessity for forced ejection of the parachute can readily be seen. In many instances of parachute-retarded missiles, the parachute, or some part of the recovery system, is expelled rearward into the wake of the missile. The wake effect tends to keep the expelled parachute component with the missile. For this reason, proper parachute deployment is always an important design consideration for any or all stages of a missile recovery system. Figure 3-4-8 shows the relationship of parachute pack ejection velocity v_{r_O}, parachute pack weight W, and missile velocity V_V. These curve calculations, based upon a study conducted by S. F. Hoerner ("Aero-Dynamic Drag" by S. F. Hoerner, Figure 7.1, Chapter VII), assume that the diameter of the ejected parachute pack is equal to that of the missile body. The diameter assumed for these calaculations is 11.5 inches.

4.2.5 PARACHUTE COMPONENTS.

4.2.5.1 Deceleration — Stage Parachute Canopies. Generally, one of the following parachute canopies will be used in initial deceleration stages:

a. FIST ribbon parachute canopy in accordance with Specification MIL-P-6635.
b. Ribless guide surface parachute canopy.
c. Ring slot parachute canopy in accordance with Specification MIL-C-8401.
d. Rotofoil parachute canopy.

Performance characteristics for these canopy types at subsonic deployment speeds are shown in Figure 3-3-7. Typical performance diagrams are presented in Figure 3-4-9.

FIST ribbon and ribless guide surface canopies have been tested in the low supersonic deployment speed range. Comparative data for these two types of parachute canopy are presented in Figure 3-4-10.

4.2.5.2 Final-Stage Parachute Canopies. Generally, the parachute selected for final stage will be one, or a cluster of the following:

a. Extended skirt parachute canopy.
b. Solid flat circular parachute canopy (generally used in clusters of three or more to achieve the desired stability).

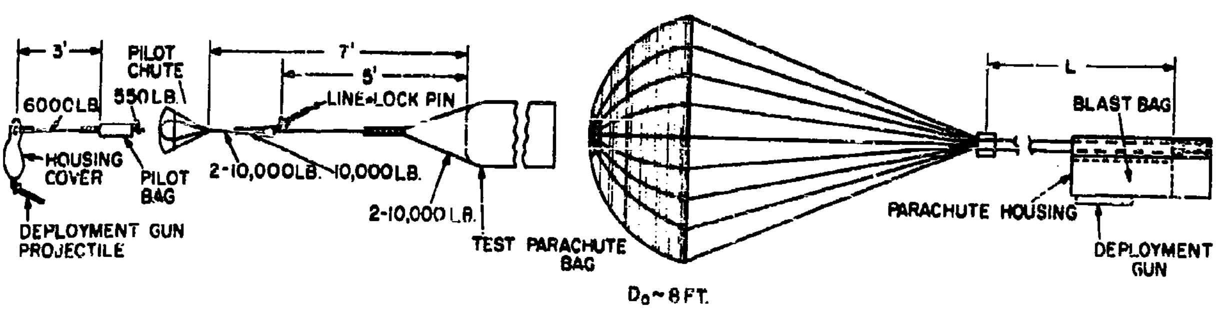


Figure 3-4-7. Parachute Deployment Sequence

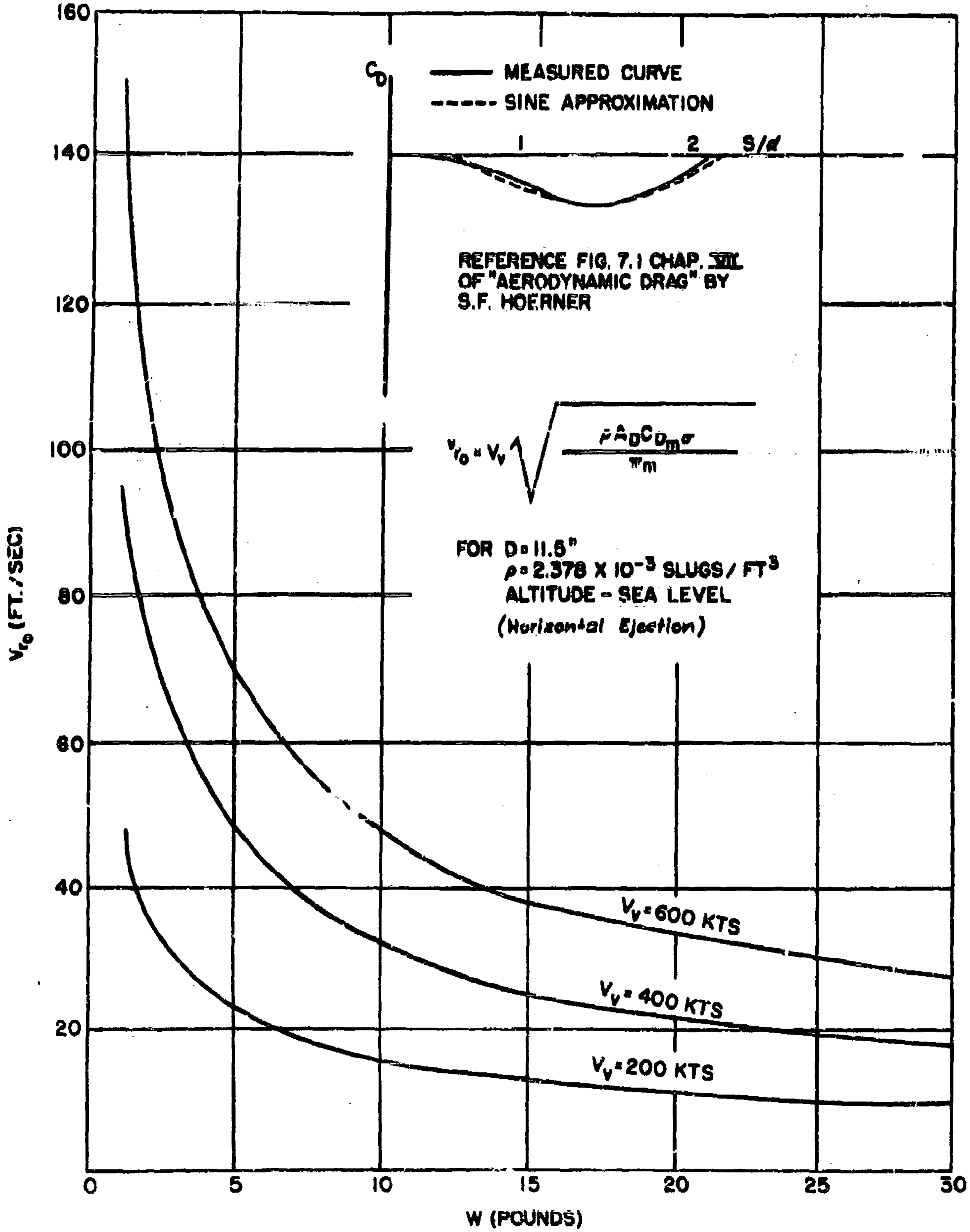
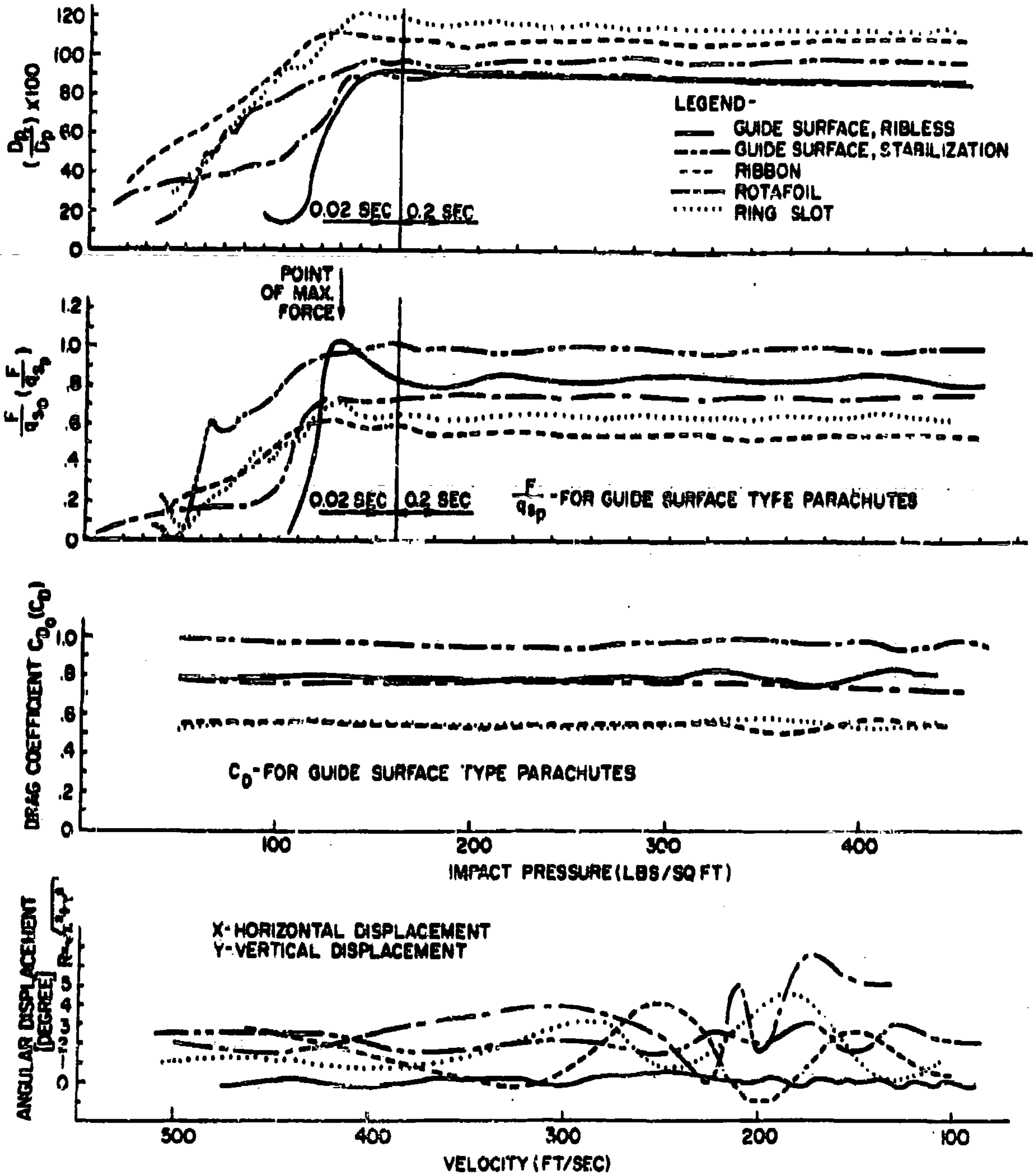


Figure 3-4-8. Relationship Between Parachute Ejection Velocity, Parachute Weight, and Missile Velocity



PARACHUTE TYPE	WEIGHT LBS	VOLUME CU FT	DIAMETER FT
GUIDE SURFACE, RIBLESS	5.75	0.26	6.50(D_p)
GUIDE SURFACE, STABLIZATION	10.00	0.48	6.50(D_p)
RIBBON	4.59	0.22	9.60(D_0)
ROTAFOIL	3.50 SWIVEL-3.125)	0.19	7.00(D_0)
RING SLOT	4.80	0.30	7.00(D_0)

Figure 3-4-9. Performance Diagrams for First-Stage Missile Recovery Parachute Canopies (Subsonic Deployment Speeds)

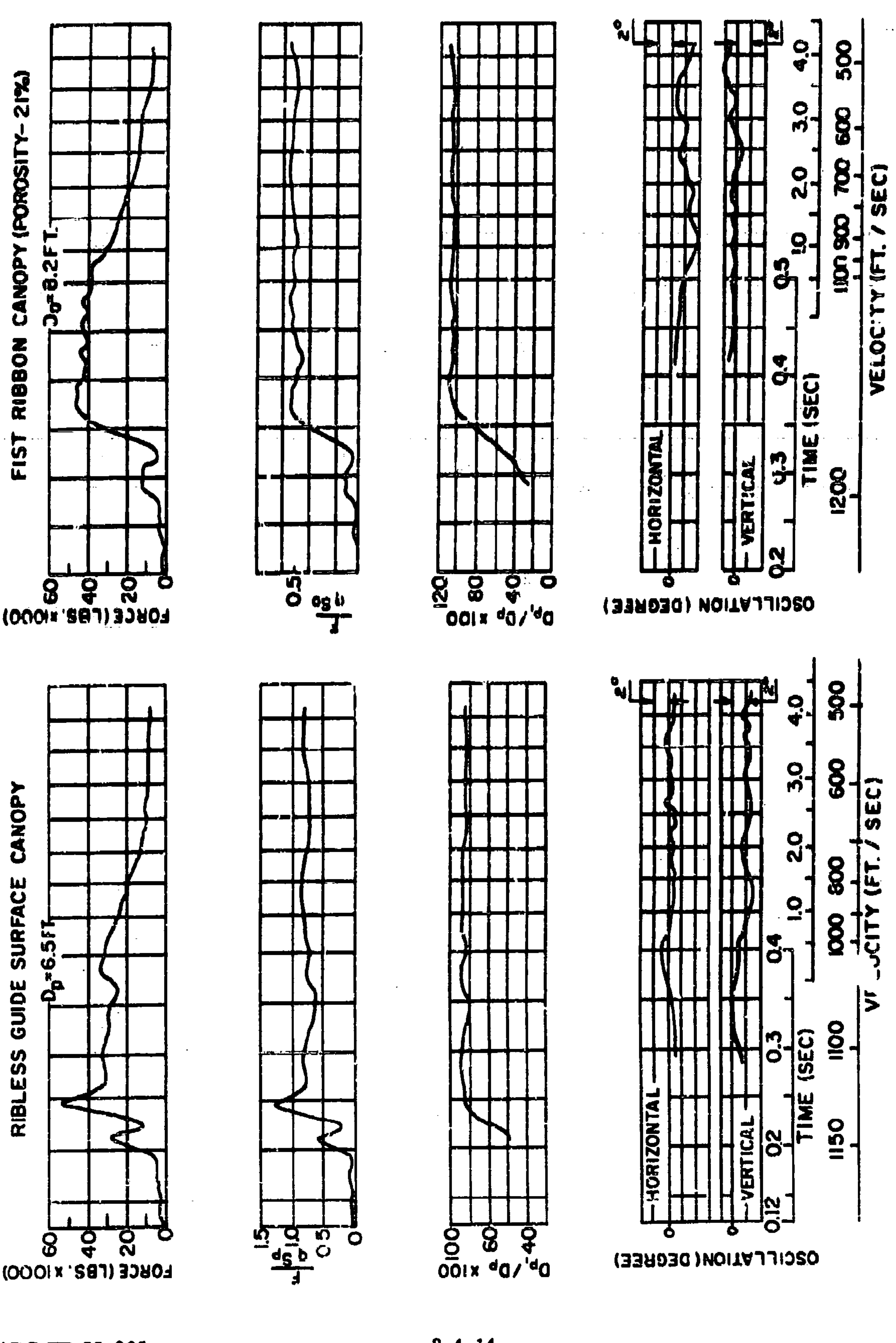


Figure 3-4-10. Comparative Characteristics for Ribbon and Guide Surface Parachute Canopies (Low Supersonic Deployment Speeds)

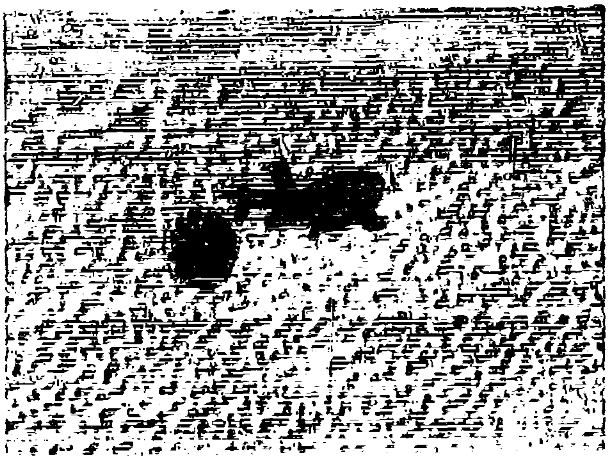


Figure 3-4-11. Typical Application of First Stage Parachute Canopy Guide Surface Type

c. Ring slot parachute canopy in accordance with Specification MIL-P-9401.
d. FIST ribbon parachute canopy in accordance with Specification MIL-P-6635.

4.2.5.3 Reefing. Skirt reefing can be used to obtain reduction of the drag area when desired. Because of a maximum speed limitation of approximately 435 knots, reefing generally cannot be used for first stage recovery. Reefing rings, in accordance with Air Force Drawing 48A7995, will generally be attached to each radial seam of the skirt. A suitable reefing line must be threaded through these rings to restrict the opening of the parachute canopy. Disreefing is accomplished by cutting the reefing line. For final-stage parachutes, the type M-2 cutter conforming to Specification MIL-C-10362 is available with time delays of 2, 4, 6, 8, and 10 seconds.

4.2.5.4 Risers and Bridles. At the present time, it is recommended that the webbing used for risers and bridles conform to Specification MIL-W-4088, except where such risers and bridles are formed by bundling the extra-long suspension lines attached to the canopy.

4.2.6 DEPLOYMENT SUBSYSTEMS.

4.2.6.1 Deployment Bags. The parachutes used for the various stages of recovery must be packed in suitably designed deployment bags, including the first-stage parachute. The bags must be designed not only for ordinary deployment and lowering of snatch force and opening shock, but also to afford protection of the parachute during ground handling and extraction from the compartment during deployment. The bag must be made of a suitable material, with necessary reinforcements, and a set of internal flaps so designed that the canopy will be retained in the bag until the suspension lines are stretched.

4.2.6.2 Forced Ejection. A forced ejection deployment system must be designed to accelerate the parachute sufficiently to assure deployment. Excessive rearward acceleration, however, may cause an increase in shock forces. (See Figure 3-4-8 for the relationship between parachute ejection velocity, parachute weight, and missile velocity.)

4.2.6.3 Pilot Parachute. Upon release of the recovery-system compartment cover, a pilot chute should be used to deploy the first-stage parachute. The design and placement of this pilot chute must be such that it will quickly inflate in the airstream and will not be blanketed by the parachute compartment cover or other parts of the recoverable body. A pilot chute should not be deployed while another parachute is functioning; entanglement of the pilot chute in the lines of the inflated parachute may prevent deployment of the next-stage parachute.

4.2.7 RELEASE AND CONTROLS SUBSYSTEMS.

4.2.7.1 Compartment Door Release. The opening of the parachute compartment door, or release of the whole door, at high aircraft speeds, is essential in a successful missile or drone recovery operation. The problem is usually not as simple as it appears. The unlatching mechanism must function reliably under various environmental extremes, such as low temperature (-65°F.), high altitude, acceleration, and vibration. The mechanism must not have an adverse effect on the performance of the missile, for example, by adding additional drag. Generally, the space allotted inside the vehicle for such a device is small. One type of device that has been used successfully is the explosive bolt. Explosive bolts are being designed for many applications.

4.2.7.2 Controls. The functioning of the recovery system must be controlled by time, altitude, or pressure, or a combination of these, arranged in order to deploy the various parachutes as desired. These devices may

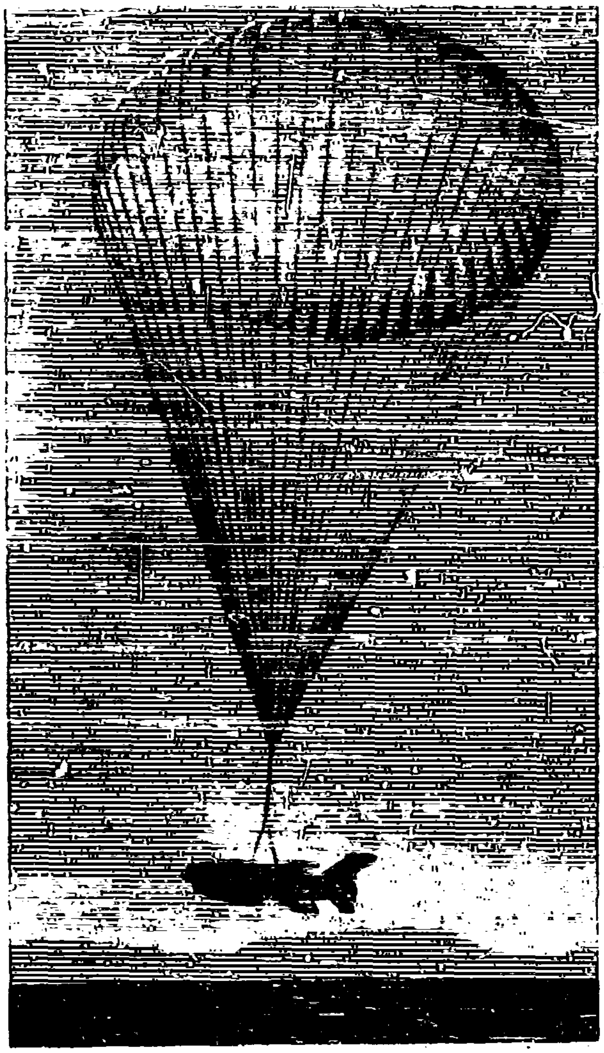


Figure 3-4-12. 66-Ft. Nominal Diameter 14.3 Percent Fully Extended Skirt Canopy Lowering a Drone (Final Stage Recovery)

perform their function either by direct mechanical linkage or through electrical circuits. Where electrical circuits are utilized, two independent parallel-circuits, complete with timers or other controls and batteries, must be provided. They must be so arranged that the failure of one circuit will not prevent the proper functioning of the recovery system as a whole.

4.2.7.3 Sequencing. Sequencing is usually accomplished by means of timers started with the initiation of recovery. Mechanical, electrical, or pyrotechnical (powder train) timers may be used if they are adaptable to the system, and provided that they meet the environmental requirements of the recoverable body. Altitude or ram pressure switches, or both, may be used for sequencing the operation of the recovery system, provided that a safety timer system is also incorporated. A suitable altitude control must be placed in series with the release system on the final recovery stage so that this stage will not be actuated higher than 15,000 feet above mean sea level. This will prevent the large final-stage parachute from opening at altitudes where opening shock may become excessive, and will also prevent excessive horizontal drift of the recoverable body while it is descending on the parachute.

4.2.7.4 Canopy Disconnect. All canopy disconnects must be mechanical, and they must be actuated either by springs or by pyrotechnic devices. A suitable device must be incorporated for releasing the final-stage parachute canopy from the recoverable body after ground or water impact to prevent the final-stage parachute canopy from dragging the missile over the ground as a result of surface winds.

4.2.7.4.1 Pyrotechnic Devices. The use of pyrotechnics for powering releases, explosive bolts, and other devices is acceptable, provided that two independent powder charges are used, either one of which will accomplish the action. In such devices, individual powder charges are ignited either by an electrical igniter or by a percussion cap.

4.2.8 LANDING SHOCK-ABSORBING COMPONENTS.

4.2.8.1 Types. In order to permit a higher rate of descent with the final-stage parachute, thus reducing to a great extent the weight and volume of the entire system, the use of landing deceleration devices must be considered. These may be penetration spikes, air bags, or crushable portions of the recoverable body itself, such as ventral fins.

4.2.8.2 Penetration Spike. This spike generally is located on the nose of the missile. It must be of sufficient strength to support the weight of the recoverable body without breaking. Consideration must be given to the horizontal forces resulting from oscillation of the parachute canopy, and drift caused by ground winds at landing.

4.2.8.3 Landing Bag. The cushion configuration that has been the most satisfactory to date consists of inflatable pneumatic bags stowed

in underside recesses of the vehicle during flight. The bags are inflated from high-pressure nitrogen or dry-air cylinders stored within the vehicle prior to ground contact. The design of a landing device of this nature must allow for the following considerations:

a. Maximum allowable forces based on the structural limitations of the vehicle.
b. Minimum dimensions of bag (stroke) based on the allowable overall structural load factors of the vehicle, the sinking velocity on the parachute canopy, and an assumed stroke efficiency.
c. Maximum working pressure based on the fabric strength and the diameter arrived at in b.
d. One or several orifices or metering devices to bleed off the pressure during the compression stroke in order to prevent the storage of kinetic energy in the compressed air, with subsequent return to the vehicle in the form of bounce.

4.2.8.4 Flotation Components. Flotation systems must be capable of floating the recoverable body for a period of one hour. This can be accomplished either by sealing compartments in the body or by providing separate, inflatable flotation equipment.

CHAPTER III

SECTION 5

AIRCRAFT DECELERATION

5.1 GENERAL.

5.1.1 EARLY HISTORY. The landing deceleration of aircraft by parachute is one of the latest and most important applications in the parachute field. The first known test using a parachute as a landing brake was made in 1923 at McCook Field, Dayton, Ohio. A standard man-carrying parachute was used to reduce the landing roll of a de Havilland biplane. Around 1933, systematic investigations were conducted at the Aeronautical Institute in Stuttgart, Germany, for the purpose of improving existing parachutes or developing a parachute which had better aerodynamic and static qualities. During the development of a parachute featuring annular slots and of parachutes made from porous materials, the "ribbon" parachute was developed. Early in 1939, a Junkers W-34 airplane made the first landing using this parachute as a landing brake. This and following tests proved that the parachute is stable, opens slowly and uniformly, produces a minimum opening shock, does not interfere with the controllability of the airplane, and is a good supplement for wheel brakes.

5.1.2 JET APPLICATIONS. The most important use for deceleration parachutes, and with it a requirement, came with the development of high-speed jet aircraft. High aircraft wing loadings resulted in high landing speeds and long landing rolls, and a means had to be developed to reduce the landing roll. The answer to this problem was the parachute. The Equipment Laboratory of the Air Research and Development Command's Wright Air Development Center, using basic information obtained from the German tests, has continued research and development in the field of parachutes for aircraft deceleration application. Many improvements have been made over original designs and various types of aircraft have been equipped with parachutes. The B-47 jet bomber is a good example of the efficient and useful operation of the parachute as an auxiliary device for decreasing landing roll. In this application, the landing roll of the B-47 is decreased 35 to 45 percent. There are two types of deceleration parachutes: one is used for aircraft landing deceleration and the other for aircraft in-flight control. An aircraft landing deceleration parachute (drag parachute) is a specially designed drag-producing device that is used to reduce the landing roll of jet type aircraft. The aircraft in-flight control parachute (approach parachute) is just what the name implies. It is a parachute that is deployed prior to landing to produce added drag, which in turn allows a steeper approach angle and more engine power to be maintained. The advantage is that safer and more accurate landings can be executed. General requirements for aircraft deceleration parachute systems are described in the Specification MIL-D-9056.

5.2 AIRCRAFT LANDING-DECELERATION PARACHUTE (DRAG PARACHUTE).

5.2.1 GENERAL. Drag parachutes are being used to decelerate aircraft during landing roll. They have proved successful for a number of conditions under which the aircraft brakes, although functioning properly, would normally be inadequate. The drag parachute has proven to be a big asset because it produces the highest deceleration force at the touchdown speed of the aircraft, where the brakes are relatively inefficient. During landings on icy or wet runways, a large percentage of the braking is accomplished by the deceleration parachute.

There are other advantages besides a reduction in landing roll obtainable with the utilization of a drag parachute. One major advantage is the increased flight safety under emergency conditions such as during landings with inoperative brakes, during aborted takeoffs, and during emergency landings on short runways. Under certain emergency conditions, it is even conceivable that the parachute could be used for rapid descent. Moreover, a monetary savings in tires and brakes is quite apparent. Using the parachute and the normal applications of brakes, the number of uses per tire can be increased five or six times over that

obtainable when landing regularly without parachute. No exact figures relating to the actual savings on brakes are available; however, it is known that brake maintenance and replacement are considerably reduced when the drag parachute is used.

5.2.2 OPERATIONAL SEQUENCE. In operation, the pilot makes a normal approach and landing. At touchdown, or very shortly thereafter, the drag parachute is deployed (Figure 3-5-1) by movement of a control handle in the cockpit. Brakes may or may not, as the operational conditions prescribe, be used to supplement deceleration. In normal operation, the aircraft is permitted to continue rolling to the turnoff intersection at a speed sufficient to keep the parachute canopy inflated. This speed, with a moderate into-wind condition, is usually below the maximum safe turnoff speed of the aircraft. If the canopy will not stay inflated, the pilot may apply brakes and maintain inflation of the canopy by increasing the engine thrust. After turnoff, the pilot maintains canopy inflation until he reaches a designated parachute release point. The parachute is released, and then is retrieved by designated personnel. The parachute should never be released on the runway or on the taxiway, where it might jeopardize other aircraft. Drag parachutes are used for the deceleration of fighter and bomber type aircraft. The relationship between landing roll and parachute canopy diameter for various μ factors is shown for a medium bomber type aircraft in Figure 3-5-2.

5.2.3 OVERALL DESIGN. The design of any drag parachute system must meet these conditions:

a. High degree of reliability.
b. High degree of canopy stability (oscillation not more than ± 5 degrees).
c. Adequate strength.
d. Low opening force of canopy.
e. High canopy drag.
f. Light weight.
g. Small bulk.
h. Not affected by environmental conditions.
i. Ease of maintenance.
j. Low cost.

During parachute deployment and steady drag, the aircraft must remain under full control of

Figure 3-5-1. B-52 Aircraft with 44-Foot-Diameter Deceleration Parachute

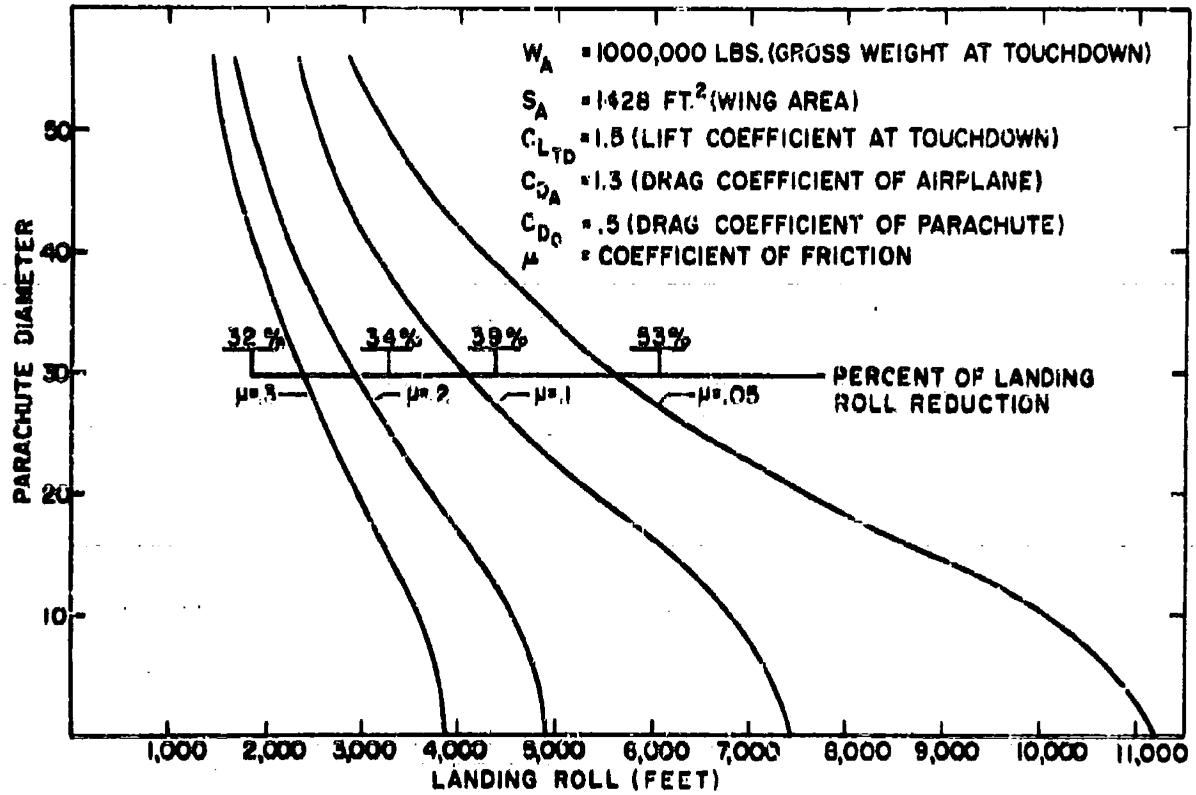


Figure 3-5-2. Landing Roll Versus Parachute Diameter and μ Factor for Medium Bomber Type Aircraft

the pilot at all times. The parachute must not interfere with the normal landing attitude of the aircraft. It must not affect the longitudinal control of the aircraft. Provision must be made for immediate release of the parachute in case of emergency. There must be no possibility of contact between the deploying or inflated parachute and the control surfaces or any other part of the aircraft.

5.2.4 DESIGN CONSIDERATIONS.

5.2.4.1 Drag Requirement. The drag requirement is generally determined by the weapons system manufacturer. The parachute system must be considered as supplementary to the available deceleration components with which the aircraft is equipped, such as flaps and brakes.

5.2.4.2 Canopy Selection. Both the ring slot and the FIST ribbon canopies have been found suitable for drag parachute application. Comparative force versus time diagrams for both types of canopies during operation on a medium bomber type aircraft are shown in Figure 3-5-3. The ring slot canopy is preferred for deceleration application because of its lower cost and ease of production and maintenance.

5.2.4.3 Size of Canopy. The size of the canopy will be determined by the drag requirement. Wake effects behind the aircraft tend to decrease the drag coefficient, C_{D_0}, which may make it necessary to use a larger parachute canopy than would be required for other applications. Longer risers tend to reduce wake losses, but they increase the bulk and weight of the system and may contribute to the dragging of the canopy on the runway during deployment. The drag coefficient C_{D_0} with regard to constructed canopy area for the FIST ribbon and ring slot canopies ranges from 0.5 to 0.6, depending upon the air flow behind the aircraft. For design purposes, a drag coefficient C_{D_0} of 0.55 for ring slot canopies and 0.5 for FIST ribbon canopies is generally used.

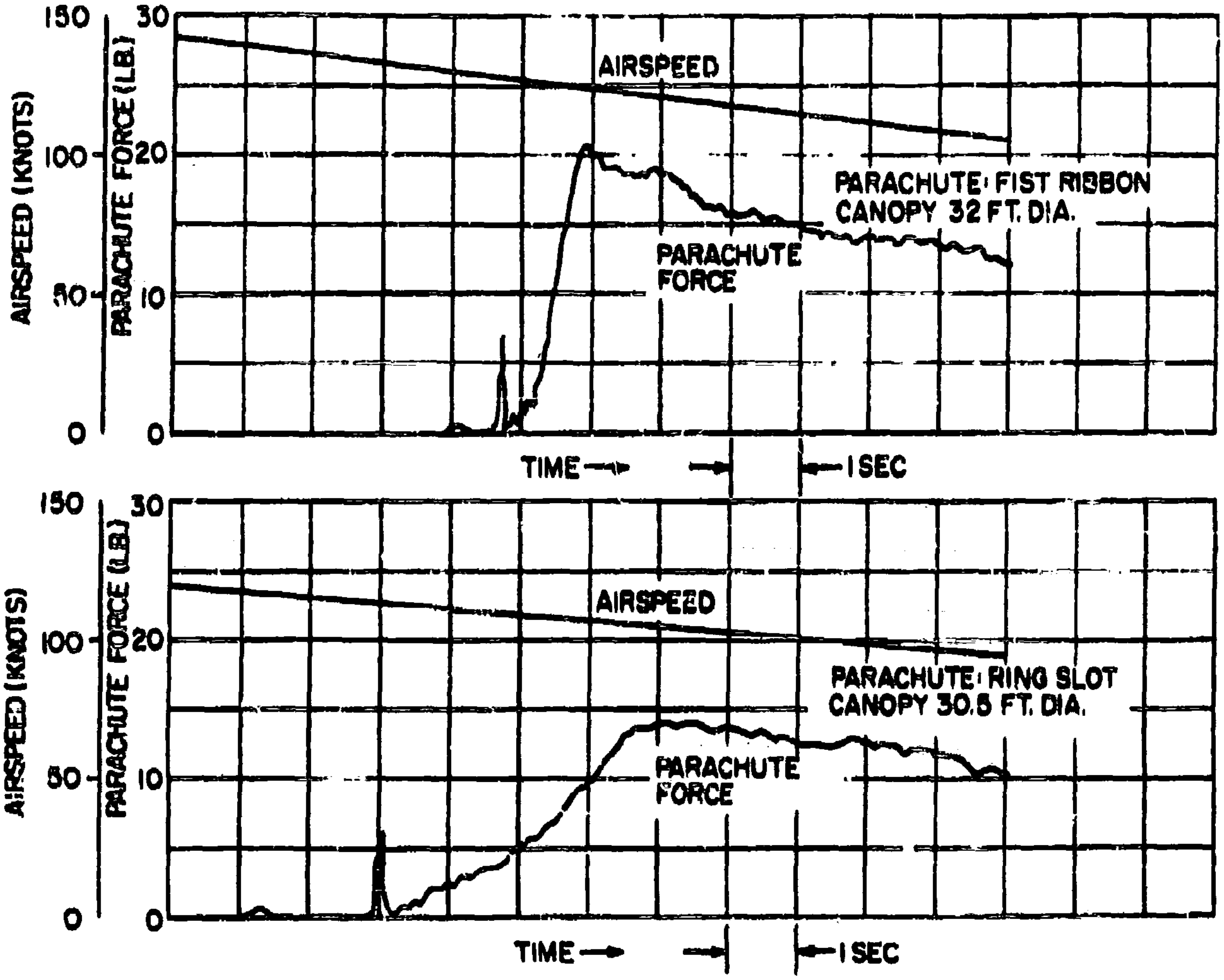


Figure 3-5-3. Force Versus Time Diagrams for Aircraft Deceleration Parachute Canopies (Application B-47 Aircraft)

5.2.4.4 Riser and Suspension Line Length. Long risers tend to reduce wake effects behind the aircraft upon the parachute canopy. Practical experience, however, has indicated that the riser length should be kept to from 1.0 to 1.5 times the constructed (flat) diameter (D) of the canopy. Length of suspension lines should be 1.0 times the constructed (flat) diameter (D) of the canopy. The most important consideration in determining riser length is the proper location of the force line of the parachute canopy with respect to the aircraft. The force line of the canopy should coincide with the line projected from the center of gravity of the aircraft through the parachute attachment point. When this is not the case, the drag force tends to raise or lower the nose of the airplane, depending on whether the canopy force line, when extended, goes above or below the aircraft center of gravity. Such a condition can have serious consequences if the parachute is deployed while the airplane still has flying speed. Even at lower speeds it can cause damage to the nose gear by exerting excessive pressure.

5.2.4.5 Parachute Compartment Location. The best location for the parachute compartment is at the very end or top of the fuselage, aft of the empennage. Such a location is not always possible, because of space limitations, heat problems, or interference with installed equipment. The location of the parachute attachment point may also have some bearing on compartment location. In some instances, it is not possible to have the parachute attachment point

within the compartment because the parachute canopy force line must pass through the center of gravity of the airplane. Parachute compartment locations at the bottom of the fuselage are particularly undesirable because the deployment bag or canopy might drag on the runway surface during the deployment process. Parachute compartment interiors must be smooth, with no protrusions or sharp edges that might catch or damage any portion of the parachute. The compartment should not be located in any section where battery acid or battery acid fumes can penetrate. The temperature in the compartment shall at no time exceed 250° F. for nylon parachutes and 350° F. for dacron parachutes.

5.2.4.6 Deployment. To obtain a uniform and trouble-free deployment of the parachute, care must be taken in the design of a suitable deployment system. In general, the canopy is packed in a deployment bag, which will protect the parachute during ground handling and extractions and will enable the using organizations to pack the parachutes in advance. A pilot chute is attached to the bag and stowed on or against the bag when the compartment door is closed. Initiation of parachute deployment is accomplished by the pilot. Upon opening of the compartment door, the pilot chute is released. The fully inflated pilot chute pulls the bag out of the compartment and deploys the canopy. In the deployed position, the components of the drag parachute appear as in Figure 3-5-4. Deployment bag and pilot chute are connected permanently to the vent lines of the canopy by means of bridle lines. The best and most reliable sequence of deployment of the canopy from the deployment bag is riser first, then the suspension lines, and finally the canopy. Each component is stored in a separate section of the bag. If the parachute compartment is close to the ground, and prohibits the use of this sequence, reverse deployment may be used. This reverse deployment, however, will result in a slight increase in opening force, and may possibly result in uneven deployments and contact of the parachute with the runway, damaging both the canopy and the deployment bag.

5.2.4.7 Reefing. Reefing is not recommended for aircraft deceleration parachutes.

5.2.4.8 Clusters. The use of parachute canopies in clusters is recommended if an individual canopy would be larger than 44 feet in diameter. Larger diameter parachute canopies tend to become heavy and bulky and present difficult problems in maintenance, packing, and installation, along with the need for expanded facilities.

5.3 AIRCRAFT IN-FLIGHT CONTROL PARACHUTE (APPROACH PARACHUTE).

5.3.1 GENERAL. This parachute is utilized for better control of the in-flight characteristics of certain types of jet aircraft, particularly

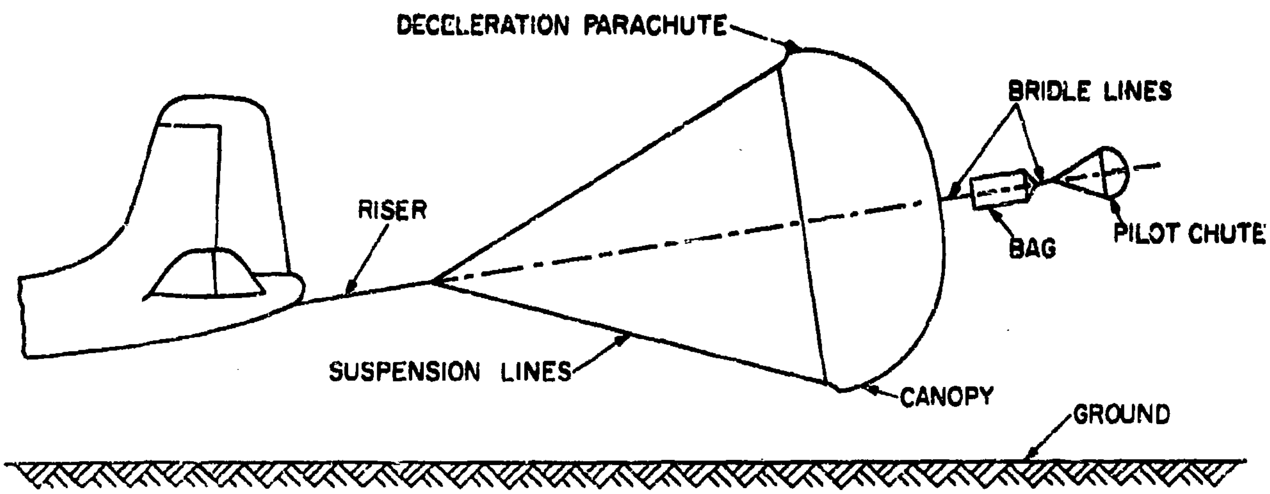


Figure 3-5-4. Schematic Arrangement of Deceleration Parachute

during landing approach. Steep rates and angles of descent are especially desirable for jet aircraft, as jet aircraft must operate at high altitudes, where their operation is much more economical than at low altitudes. In order not to exceed speed limitations, some modern jet aircraft must begin descents from high cruising altitudes when still a considerable distance out from the airbase. The same jet aircraft can start their descent relatively close to the airbase when using an approach parachute. Use of an approach parachute facilitates instrument letdowns, particularly GCA, as the additional drag permits a rapid deceleration, steepens the glide path, and also prevents overcontrol. The higher throttle setting, which may be used during approach by virtue of the added drag, also permits a more rapid response of the aircraft in the event of emergency or go-around. The B-47 aircraft was the first aircraft for which an approach parachute system was adopted. An approach parachute on the B-47 aircraft is shown in operation in Figure 3-5-5.

5.3.2 OVERALL DESIGN. The design of any inflight control or approach parachute system must meet the requirements as described in paragraph 5.2.3 for drag parachutes.

5.3.3 DESIGN CONSIDERATIONS. At the present time, approach parachutes are standard on the B-47 aircraft only. Some of the considerations given hereafter are applicable particularly to that type of aircraft. Any systems design for another type of weapons system may require a further consideration.

5.3.3.1 Drag Requirement. The drag requirement for the approach parachute system will have to be established by the prime contractor

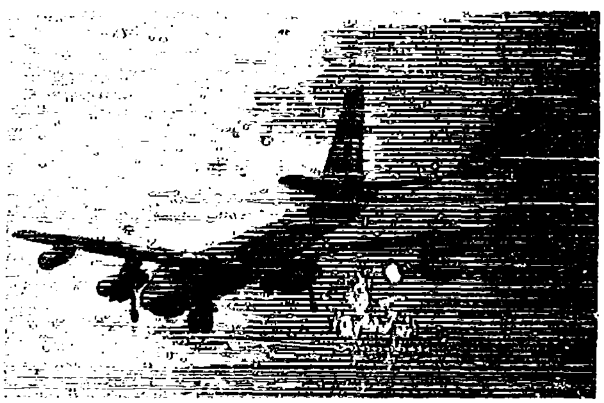


Figure 3-5-5. Approach Parachute on B-47 Aircraft

of the weapons system. For the B-47 aircraft, the drag of the approach parachute is of such a value, that the aircraft, in landing configuration, is able to achieve a rate of climb of at least 500 feet per minute at the optimum designed landing gross weight at sea level. Figure 3-5-6 shows typical climb performance curves for a medium bomber type aircraft using approach parachutes with different drag areas.

5.3.3.2 Canopy Selection. The ring slot canopy should receive primary consideration in any aircraft approach parachute system. Tests have indicated that it satisfies desired stability requirements. Its cost and ease of production and repair give it a decided advantage over the FIST ribbon canopy. The FIST ribbon canopy should be considered for applications in which the deployment speed requirement is higher than the design limits of the ring slot canopy. The application of guide surface type canopies for approach parachute systems is currently being investigated. Other types of parachute canopies are ruled out for reasons of stability, cost, bulk, or strength factor.

5.3.3.3 Size of Canopy. The size of the canopy is determined by the drag requirement. The drag coefficient C_{D_0} for the FIST ribbon and ring slot canopies ranges from 0.5 to 0.6, depending upon the air flow behind the aircraft. For design purposes, a drag coefficient C_{D_0} of 0.55 for ring slot canopies and 0.5 for FIST ribbon canopies is generally used. A typical force-time diagram obtained during the deployment and steady drag of a 12-foot-diameter ring slot parachute behind a medium bomber type aircraft traveling at an airspeed of 147 knots is shown in Figure 3-5-7.

5.3.3.4 Riser and Suspension Line Length. If both in-flight control and deceleration parachutes are used, the position of the skirt of the deceleration parachute is the determining factor for the riser length of the approach parachute, as the skirt of each parachute canopy must be equidistant from the aircraft. If an approach parachute only is used, the length of the riser should in general be 1.0 to 1.5 times the constructed (flat) diameter (D) of the canopy. Suspension line length should be 1.0 times the constructed (flat) diameter (D) of the canopy.

5.3.3.5 Parachute Compartment Location. The approach parachute compartment may be located on the top, side, or bottom of the aft end

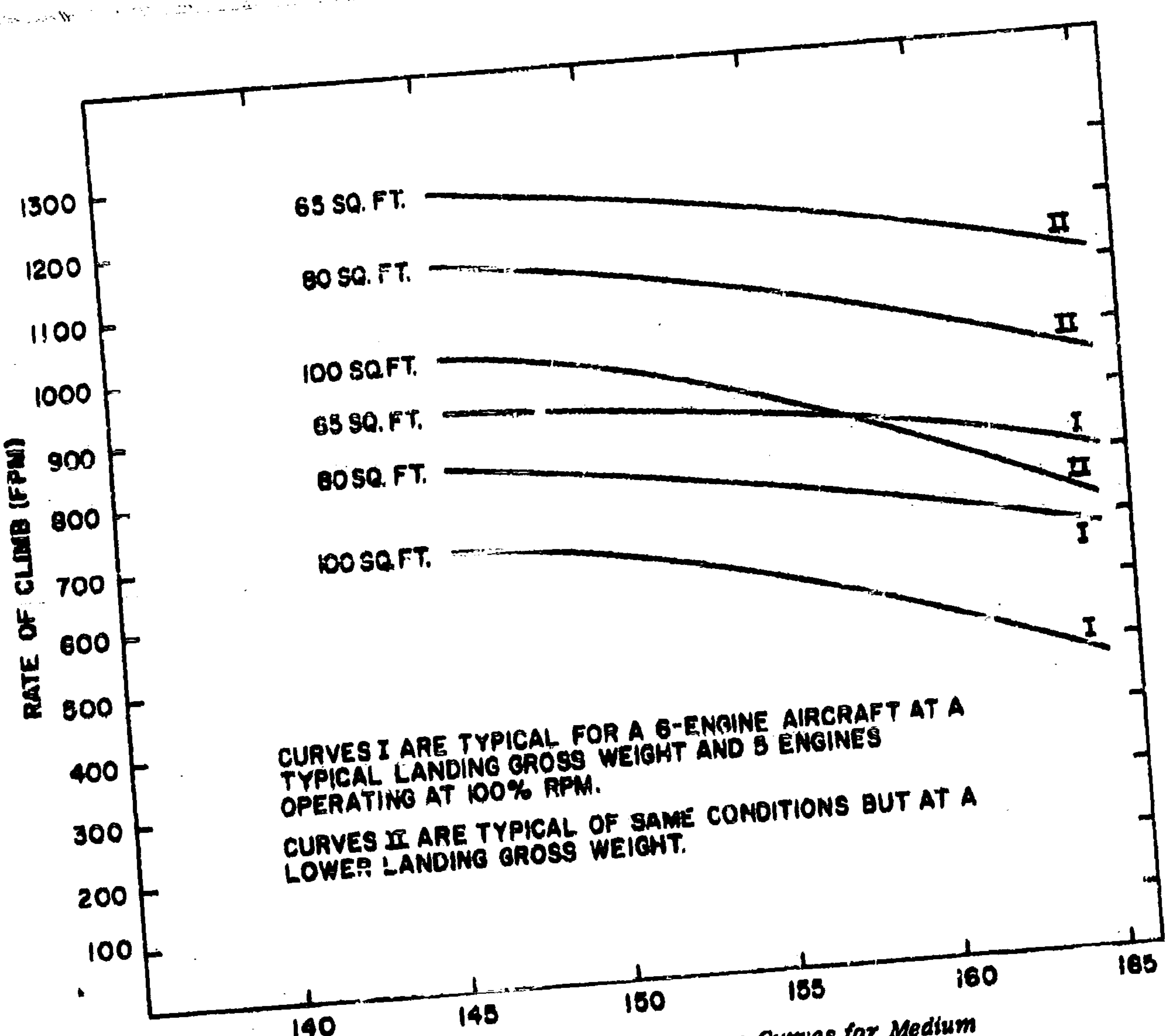


Figure 3-5-6. Typical Climb Performance Curves for Medium Bomber Type Aircraft with Approach Parachute

of the aircraft. The location of the parachute attachment point is an important factor in determining the compartment location. (Figure 3-4-8.) Tests conducted with a medium bomber type aircraft have indicated that a location of the attachment point about 2 feet to the side of the aircraft centerline does not appreciably affect the longitudinal control. On aircraft with a relatively short fuselage section, such as a flying wing type, side attachment requires further investigation. In some cases, the attachment point must be located in a area away from the compartment. There is little likelihood that the canopy will be burned by the jet exhaust, while riser and suspension lines may be exposed to excessive temperatures, damaging and eventually causing failure of the parachute. This condition may be overcome by the use of steel cable risers, if the limited bending radius of steel cable does not create a stowage problem. All compartments should be designed to permit parachute deployment rearward along a line parallel to the flight path. Compartment interiors must be smooth, with no protrusions or sharp edges which might catch or damage any protion of the parachute. The compartment should not be located in any section where battery acid or battery acid fumes can penetrate. Bottom compartments may utilize an elevator to lower the parachute directly into the airstream. The temperature in the compartment shall at no time exceed 250° F. for nylon parachutes and 350° F. for dacron parachutes.

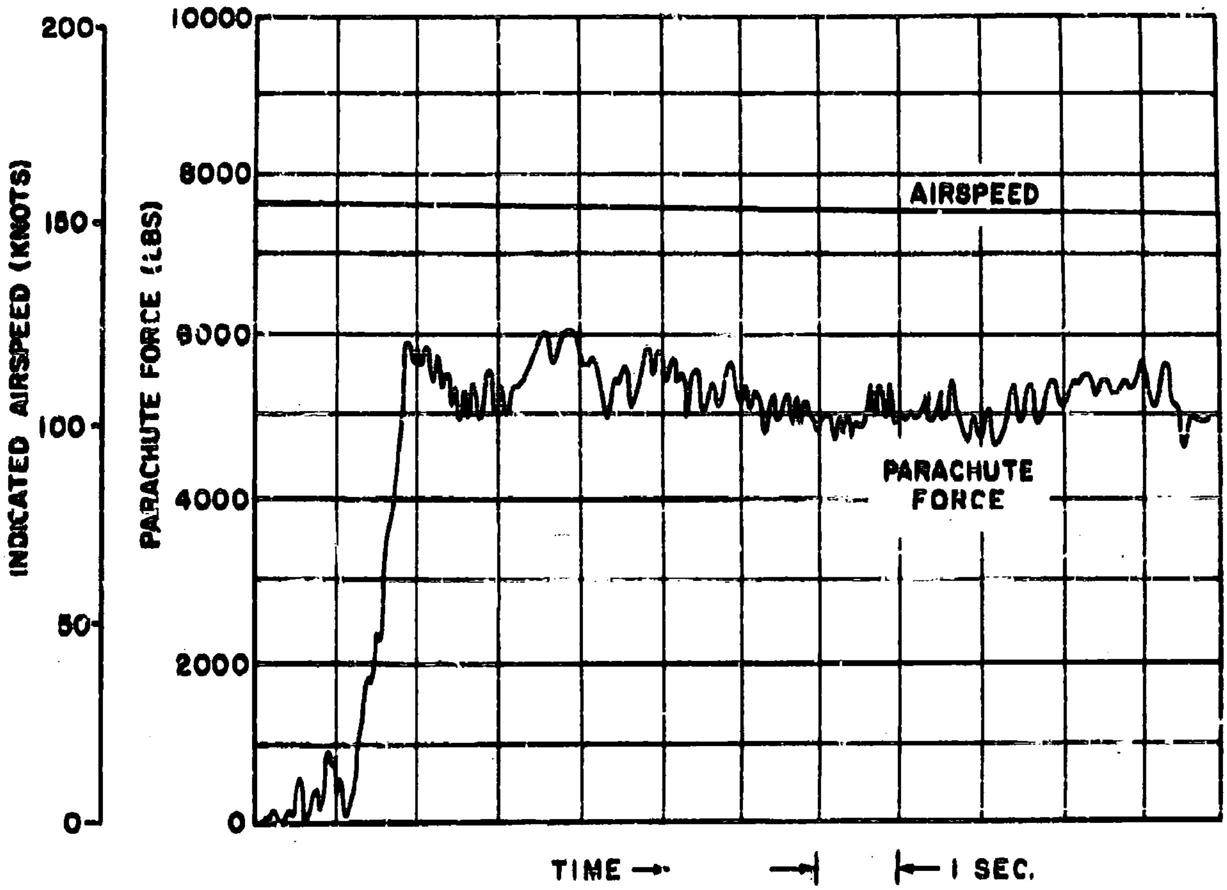


Figure 3-5-7. Typical Force versus Time Diagram for an In-Flight Control Parachute Canopy

5.3.3.6 Deployment. In all installations, deployment bags and spring-loaded pilot chutes should be used. Deployment bags should be used to facilitate the maintenance and installation of the parachutes in the aircraft and to insure orderly deployment. Riser-first deployment, in which the bag travels with the canopy, should be used.

5.3.3.7 Reefing. Generally, reefing is not recommended for aircraft in-flight control parachutes. However, a permanent reefing line may be installed to achieve greater stability or to reduce the drag area of an existing canopy, which unreefed creates only slightly higher drag than is desired for the particular application. For instance, the standard approach parachute for the B-47 aircraft incorporates a 15.5-foot-diameter ring slot canopy which is slightly reefed by means of a 27.5-foot reefing line. This reefing line is permanently installed at the skirt of the canopy. Thus, drag area is decreased slightly and a higher degree of stability is obtained.

5.4 DECELERATION PARACHUTE CONTROL SYSTEM.

The control system for aircraft deceleration parachutes must be designed to reliably and repeatedly perform a number of functions, two of which occur in sequence in one operation. When deployment of the parachute is initiated by pulling the control handle in the pilot's cockpit, the mechanism must lock the parachute to the attachment point on the aircraft; then, after positively locking the parachute, it must open the compartment door. The attachment hook shall remain open as long as the control handle is in stowed position. This is a safety measure to allow the parachute to drop free in the event the compartment door is accidentally opened by means other than actuation of the control handle while the aircraft is

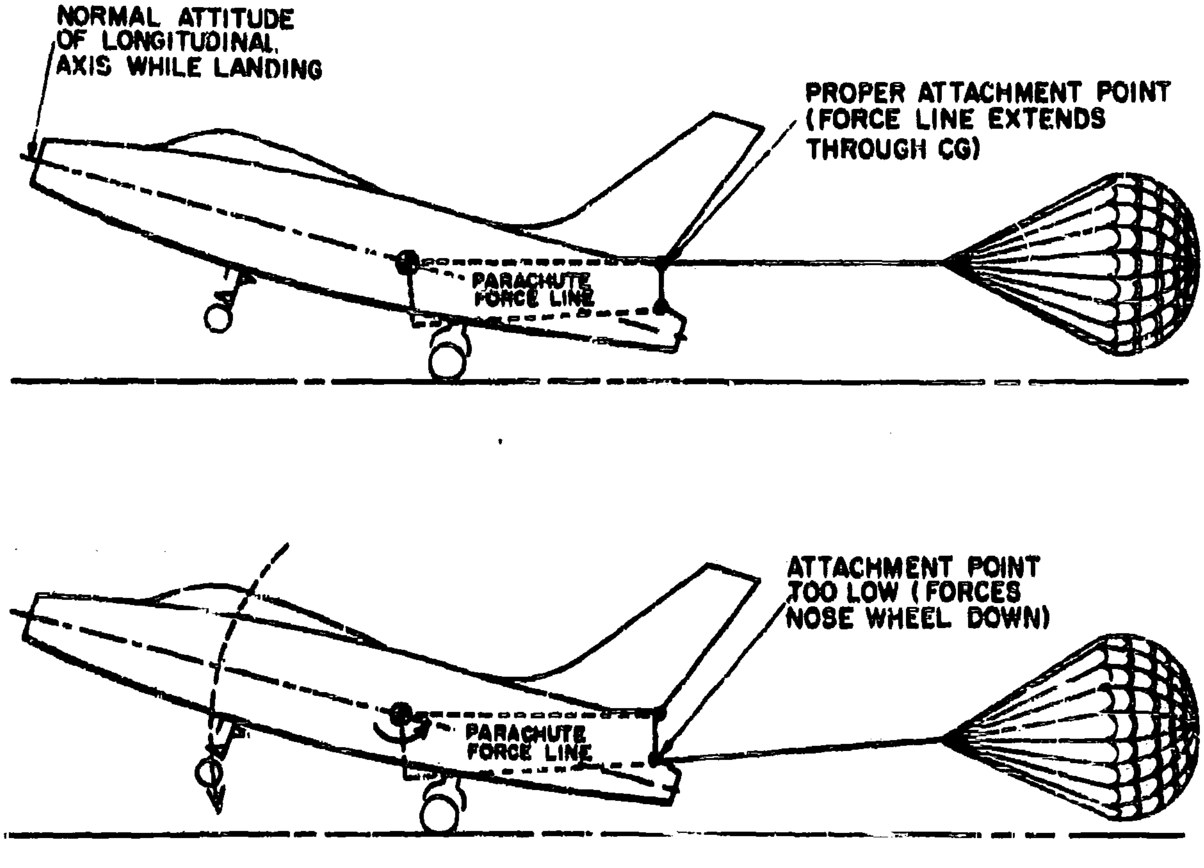


Figure 3-5-8. Alignment of Parachute Canopy Force Line, Parachute Attachment Point, and Aircraft Center of Gravity

in flight. Jettison of the parachute from the aircraft may be accomplished by using either a separate control cable or the same control cable with the handle moved into a different position. Experience has indicated the desirability of using a two-cable system for bomber type aircraft and a single-cable system for fighter type aircraft. A mechanical system is preferred because of simplicity and positive operation. One disadvantage of a mechanical system is the difficulty of routing the control cable in such a manner that it does not interfere with crew or equipment, yet will operate with a minimum of friction and without loss of reliability due to detrimental effects of environment. In installations where a mechanical system is impractical, a hydraulic, electric, or pneumatic system may be utilized.

CHAPTER IV

PARACHUTE DATA CALCULATIONS

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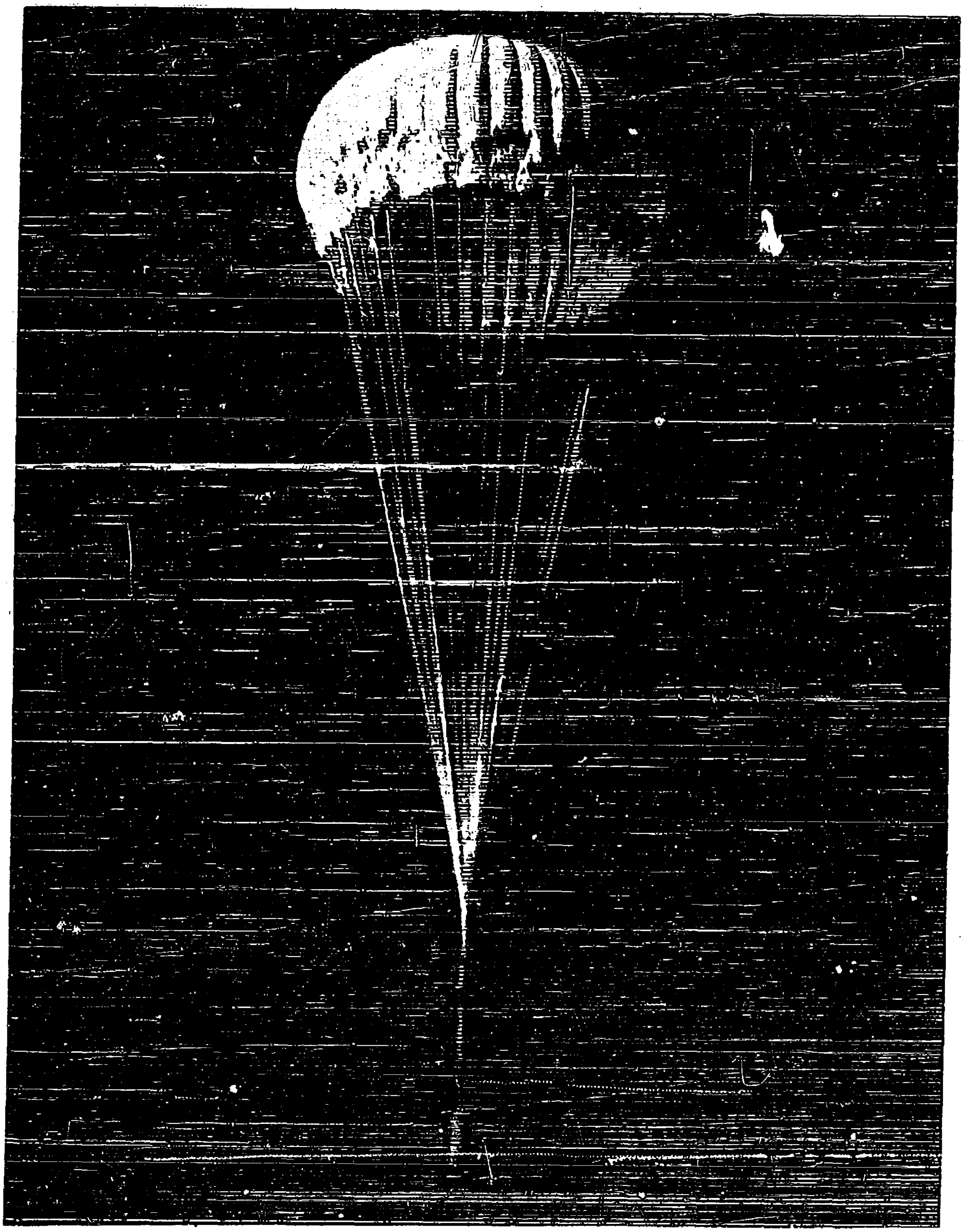

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CHAPTER IV

SECTION 1

PARACHUTE SNATCH FORCES

1.1 SNATCH FORCE.

All parachute openings create a force known as "snatch" force. It can be defined as the force imposed upon the suspended load by the parachute to accelerate the mass of the parachute from its final velocity at line stretch (or snatch) to the velocity of the suspended load. Snatch force arises from the comparatively rapid deceleration of the deploying parachute in relation to the slow deceleration of the suspended load. A differential velocity thus exists, and must be reduced to zero.

1.2 GENERAL CONSIDERATIONS.

1.2.1 Fortunately, snatch forces are imposed at the completion of suspension-line deployment, prior to actual inflation of the canopy. Thus, snatch force and opening shock (Section 2) are not additive forces; rather, they follow closely. (See Figures 4-1-1 and 4-1-2.) At comparatively low speeds, and with present canopy designs, snatch forces do not exceed opening shock. With low-shock canopies now in use or under design, however, it is felt that the limiting factor on future parachute operation will be snatch force. Opening shocks can be reduced considerably by special reefing, venting, collapsing, or squidding canopy designs. Snatch forces can be reduced only by controlled deployment (a very difficult process if the deployment system must be usable over a large speed range), by reduction of parachute weight, by reduction of uninflated canopy drag area, and by reduction in pilot-chute drag area. The latter two factors are intimately connected with proper deployment, and cannot be reduced beyond a certain limit without serious adverse effects on deployment and reliability.

1.2.2 Figure 4-1-1 shows a record of force versus time in the opening of a standard 28-foot parachute canopy at 260 knots. Snatch force and opening shock are indicated.

1.2.3 Figure 4-1-2 shows a record of force versus time in the opening of a standard 28-foot parachute canopy with reefing rings at 260 knots. It will be noted that snatch force here considerably exceeds opening shock. Reefing rings have so altered the canopy that it is a low-shock design. The primary maximum force to be considered thus becomes snatch force.

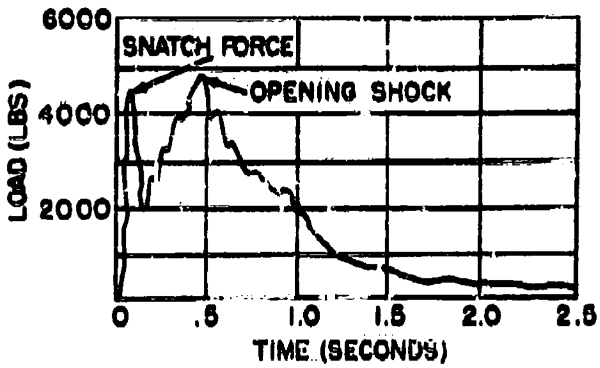

Figure 4-1-1. Force Versus Time in the Opening of a Standard 28-Foot Parachute Canopy, at 260 Knots

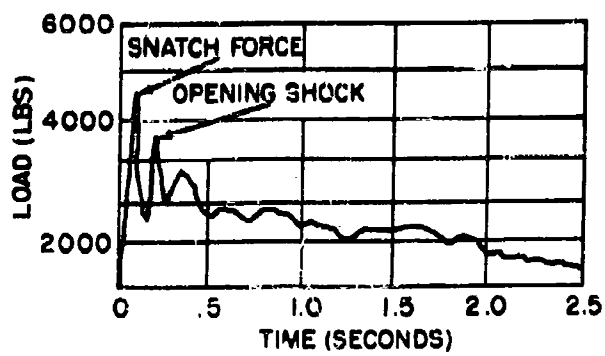

Figure 4-1-2. Force Versus Time in the Opening of a Standard 28-Foot Parachute Canopy with Reefing Rings, at 260 Knots

1.3 CALCULATION OF SNATCH FORCE.

1.3.1 Upon full extension of the suspension lines, the energy ΔE is transmitted to the suspended load if

$$\Delta E = \frac{W_c}{2g} \Delta V^2$$

where

W_c = weight of the canopy cloth area, lb., including the weight of the suspension lines across the cloth area, but not including the weight of the free length of suspension lines

g = gravity

ΔV = differential velocity between the center of gravity of the parachute canopy before and immediately after the snatch

1.3.2 If no special shock absorbers are installed, the force developed must be transmitted through the suspension lines. Being elastic, the lines extend, and transmit a tractive force to the parachute canopy and to the suspended load. Thus,

$$\Delta E = \int_0^{\epsilon} P \, d\epsilon$$

where

P = momentary tractive force in the suspension lines, lb.

ϵ = elongation of the suspension lines, ft.

1.3.3 For normal nylon suspension lines, it can be assumed that the force versus elongation curve will be approximately linear. The following equation can then be written:

$$P = \frac{P_{max}}{\epsilon_{max}} \epsilon$$

therefore

$$\Delta E = Z \frac{P_{max}}{\epsilon_{max}} \int_0^{\epsilon} \epsilon \, d\epsilon$$

where

Z = number of suspension lines

P_{max} = breaking strength of suspension line, lb.

ϵ_{max} = maximum elongation of suspension lines, ft.

Revising the equation, we obtain

$$\epsilon = \sqrt{\frac{2 \Delta E}{Z (P_{max}/\epsilon_{max})}}$$

and the highest snatch force thus is

$$P = \sqrt{\frac{\frac{W_c}{g} \Delta V^2}{Z(P_{max}/\epsilon_{max})}} \, Z \frac{P_{max}}{\epsilon_{max}}$$

$$= \sqrt{\frac{W_c}{g} \Delta V^2 \, Z \frac{P_{max}}{\epsilon_{max}}}$$

1.3.4 The last equations can be solved without difficulty if ΔV is known. The calculation of ΔV is determined by circumstances, and some suitable assumption must be made. Therefore, the graphs at the end of this section, representing a number of solutions, are given. By use of these graphs it is possible to estimate the snatch force quickly and with fair accuracy. Figures 4-1-11, 4-1-12, 4-1-13, 4-1-14, and 4-1-15 show the time t required for two bodies with varying drag loading K to separate for a certain distance d, provided both have a launching speed of V_o and both are decelerated only by their individual drags. Knowing the time t, we may calculate the differential velocity ΔV by means of the following formula:

$$\Delta V = V_o^2 \frac{tK_b(n - 1)}{1 + V_o tK_b(n + 1) + V_o^2 n K_b^2 t^2}$$

To attain wider application, the combined values K and n have been used in both the graphs and the formula. The following are implied in paragraphs below:

$$K_b = \frac{C_{D_b} S_b \gamma}{2W_b} \text{ for the suspended load}$$

where

K_b = drag loading of the suspended load, ft.$^{-1}$

C_{D_b} = coefficient of drag of the suspended load

γ = specific weight of air, lb. per cu. ft.

W_b = weight of suspended load, lb.

S_b = aerodynamic area of the suspended load

$$K_p = \frac{C_{D_o} S_o \gamma}{2W_p} \text{ for the parachute}$$

where

K_p = drag loading of the uninflated parachute, ft.$^{-1}$

$C_{D_o}S_o$ = average drag area of the uninflated parachute plus drag area of the pilot chute, sq. ft.

W_p = weight of the canopy cloth area plus weight of external suspension lines, lb.

$$n = \frac{K_p}{K_b}$$

d = distance from the center of gravity of the canopy to the suspension point on the load

The present calculating system is based on a few physical assumptions and simplifications. To the extent that it can be assessed, it gives results with fair accuracy. The system is under continuing study, and it may be necessary to revise or to supplement some assumptions. Present assumptions of the drag of the uninflated parachute plus pilot chute, in particular, are not based on measured data, and cannot be considered definite. Until more accurate data is available, however, such assumptions must be made.

1.4 EXAMPLE OF SNATCH FORCE DETERMINATION.

1.4.1 If it is assumed that the following conditions exist, the snatch force for these conditions can be calculated.

W_b = 200 lb.
$(C_D S)_b$ = 4 sq. ft. (for suspended load)
W_p = 10 lb. (for parachute canopy)
W_c = 7.5 lb. (for canopy cloth area only)
$(C_D S)_s$ = 3 sq. ft. (for the uninflated parachute canopy plus pilot chute)
Z = 24 suspension lines
P_{max} = 550 lb., breaking strength, suspension lines
l_s = 20 ft., length of suspension lines
ϵ_{max} = 0.4 × 20 ft. = 8 ft., maximum elongation of suspension lines (550-lb. suspension lines elongate 40 percent maximum)
V_o = 130 knots launching speed
γ = 0.07651 lb. per cu. ft. specific weight of air, sea level
d = 21 ft. from center of gravity of canopy to suspension point of load

1.4.2 Specific values, after solution, are as follows:

K_b = 7.65 × 10^{-4} ft.$^{-1}$
K_p = 115 × 10^{-4} ft.$^{-1}$
n = 15
d = 21 ft.

1.4.3 Figures 4-1-11, 4-1-12, 4-1-13, 4-1-14, and 4-1-15 show the distance d in feet that bodies with varying drag loadings K will travel (decelerate) within a certain time t if launched at various velocities. Using Figure 4-1-11, and assuming that the K of the suspended load is always considerably less than that of the parachute, the distance d = 21 ft. (refer to paragraph 1.4.1) may be measured on the ordinate of Figure 4-1-11 by divider. Since it is desired to determine the time t corresponding to K_b = 7.65 × 10^{-4} and K_p = 115 × 10^{-4}, and there is no curve for K = 115 × 10^{-4}, it is necessary to estimate a value of t using the curves K = 122 × 10^{-4} and K = 106.5 × 10^{-4}, between which a curve of K = 115 × 10^{-4} would lie. With the dividers, the distance of 21 feet should be laid out parallel to the ordinate, with the divider based on the K of the body; in this case the value is 7.65 × 10^{-4}. The second arm of the divider falls upon the curve of K = 122 × 10^{-4} at a value of t = 0.35 second. Repeating this procedure, it is found that if the curve K = 106.5 × 10^{-4} is used, a value of t = 0.375 is obtained. The required value of t falls between these two values and is estimated to be 0.36 second.

1.4.4 For t = 0.36 second and the given values K_b = 7.65 × 10^{-4} and n = 15, the differential velocity ΔV can be calculated by use of the formula for ΔV noted under paragraph 1.3.4. Thus

ΔV = 92 ft. per sec.

1.4.5 Knowing ΔV, we may insert it in the formula noted under paragraph 1.3.4, and obtain a snatch force of P = 1,810 pounds.

1.4.6 Calculated with the same system, the same chute dropped at 260 knots will develop a snatch force of approximately 3,700 pounds.

1.4.7 As already noted in paragraph 1.3.4, the assumption of the average drag area of the uninflated parachute canopy is not reliable, because normal canopies can be partially inflated during the stretching time. The snatch force can thus be increased to a great extent. For example, if the average drag area of the canopy noted above is increased to 6 square feet, snatch force will be approximately 1,900 pounds at 130 knots and approximately 4,500 pounds at 260 knots.

1.4.8 In practice, measured values will deviate considerably, both above and below calculated values, if a simple, uncontrolled deployment system is utilized. Controlled systems, such as those employing bags or sleeves or other devices, yield more consistent and predictable values.

1.5 MEASURES TO REDUCE SNATCH FORCE.

1.5.1 GENERAL. The preceding examination demonstrates that snatch force can rise to dangerous magnitudes. Methods of reduction are listed below.

1.5.1.1 The drag area $(C_DS)_o$ of the uninflated canopy must be reduced to the minimum, and any tendency to partially inflate previous to line stretch must be eliminated.

1.5.1.2 This may be accomplished by use of a device known as a skirt hesitator, which restricts the skirt of the parachute canopy and prevents canopy inflation until the completion of the snatch. Tests of the hesitator have been successful at high and low speeds (100 to 350 knots).

1.5.1.3 Decrease of the distance d (line length) will reduce snatch force.

1.5.1.4 Use of suspension lines with high elongation will decrease the peak force at snatch.

1.5.2 NEW PACKING METHODS.

1.5.2.1 Rolling. When the canopy of a parachute is packed in a roll, rather than in accordion folds, the mass of the canopy is not fully effective at the snatch. Instead, a portion of the mass unrolls, and only a fraction of the total mass is accelerated linearly with the suspension lines. The remainder of the canopy begins a rotating action which distributes the total force over a longer time base, reducing peak forces considerably. Experiments have proven that the maximum snatch force is reduced by approximately 40 percent if roll packing and deployment are used. It is also possible to roll a portion of the suspension lines in the same manner. Experiments with the second system show that snatch forces can be reduced by 60 percent. The second system, however, is not reliable.

1.5.2.2 Bag Deployment. Experiments with man-carrying parachutes showed that very heavy and undesirable snatch forces were obtained at deployment speeds of 130 knots. A number of methods for reducing this force were employed, but none was as successful, at speeds of up to 350 knots, as bag deployment. Sequence of operation of the bag deployment is shown in Figure 4-1-3. Assembly and packing details and methods are illustrated by Figures 4-1-6, 4-1-7, 4-1-8, 4-1-9, and 4-1-10. Shown in Figures 4-1-4 and 4-1-5 are comparative force versus time diagrams developed by a parachute canopy with and without bag deployment. It should be noted that the recordings are average and typical and are not isolated examples. The mouth sections of deployment bags may be closed by any one of several methods:

a. The line-tie method illustrated in Figures 4-1-6 through 4-1-10 is the simplest, but it allows direct entrance of high-velocity air into the bag.
b. Flap closures, similar to those used on sleeves, have been tested successfully.
c. Closure flaps have also been held in position by stowing suspension lines over the flaps themselves.

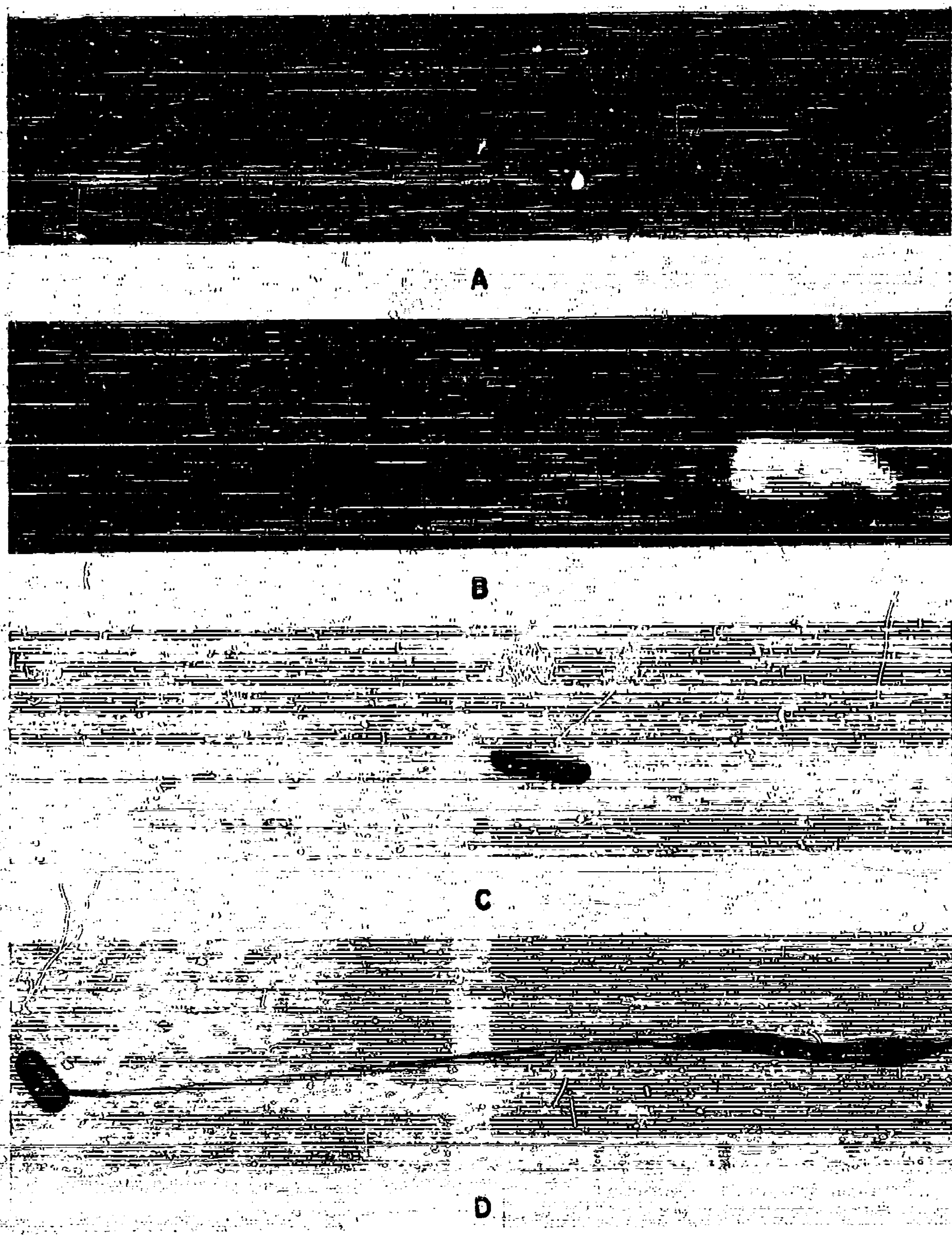

Figure 4-1-3. Photographs A and B Show Deployment of a Flat Circular Parachute, with Bag, at 260 Knots. Bag and Pilot Chute Show Clearly in A. Photographs C and D Show Initial Deployment of a Flat Circular Parachute, Equipped with Bag, at 305 Knots. Pilot Chute Was Used.

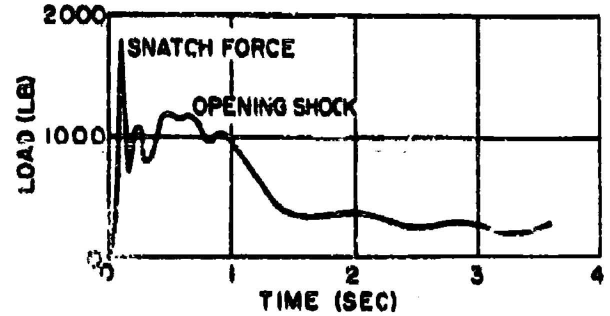

Figure 4-1-4. Force Versus Time Diagram of a 28-Foot Flat Circular Parachute Canopy No Bag Deployment

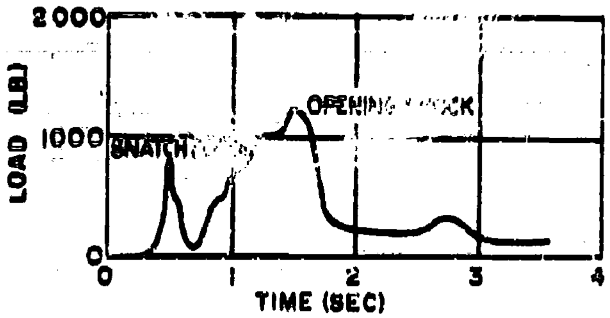

Figure 4-1-5. Force Versus Time Diagram of a 28-Foot Flat Circular Parachute Canopy Using Bag Deployment

Figure 4-1-6. Components of the Bag Deployment System Are Shown As:

A — Pilot-Chute Bridle Line
B — Bag Bridle Line
C — Bag
D — Pilot Chute
E — Vent of Main Parachute Canopy

Figure 4-1-7. The Main Parachute Canopy Is Folded Normally, Then Folded Again in the Manner Shown, As It Is Packed into the Bag

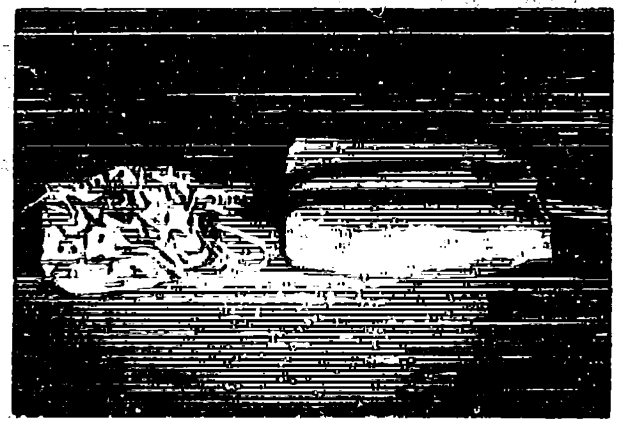

Figure 4-1-8. The Canopy Has Been Completely Packed and the Mouth of the Bag Tied Closed

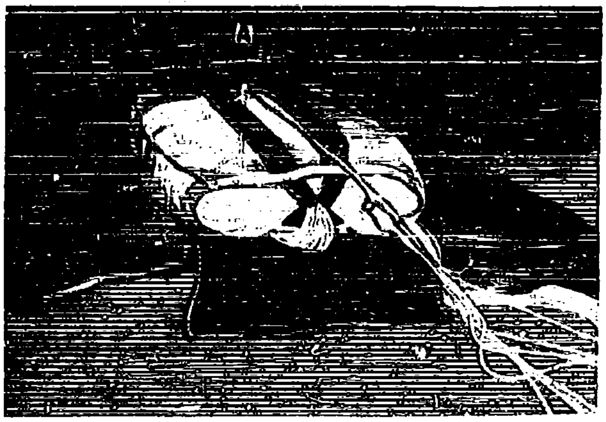

Figure 4-1-9. Suspension Lines Are Run Through the Tie Formed by Four Reinforcing Webbings, to Which the Pilot-Chute Bridle Line Is Attached at A. Lines Are Normally Stowed in Line Retaining Loops Under the Bag

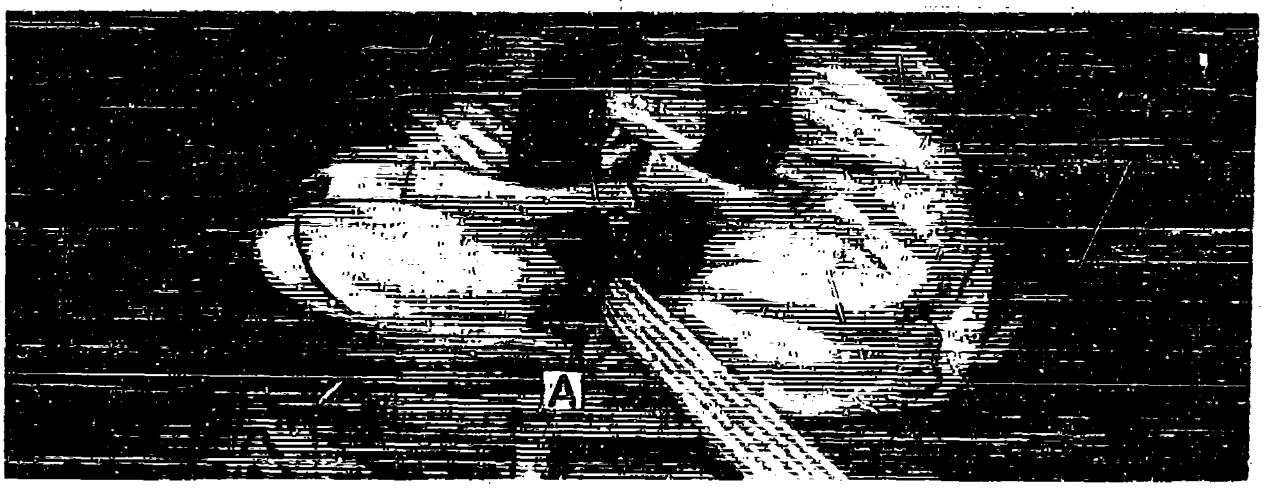

Figure 4-1-10. Tie Loops on Reinforcing Webbings Are Shown at A. Three Turns of 5-Cord Hold the Canopy in Position Until Lines Are Stretched and Pilot-Chute Drag Breaks the Cord

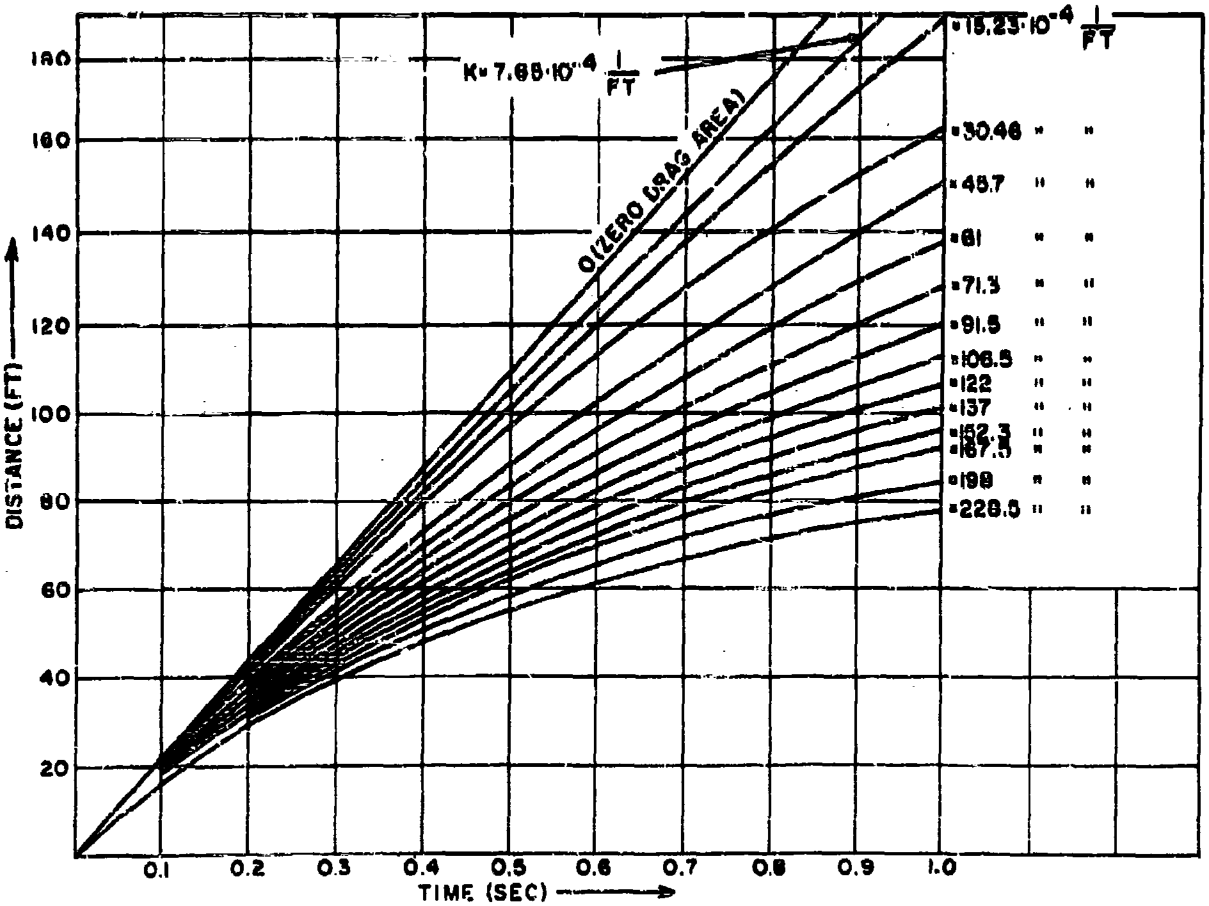

Figure 4-1-11. Distance of Travel of Bodies with Various Drag Loadings, Launched at 130 Knots

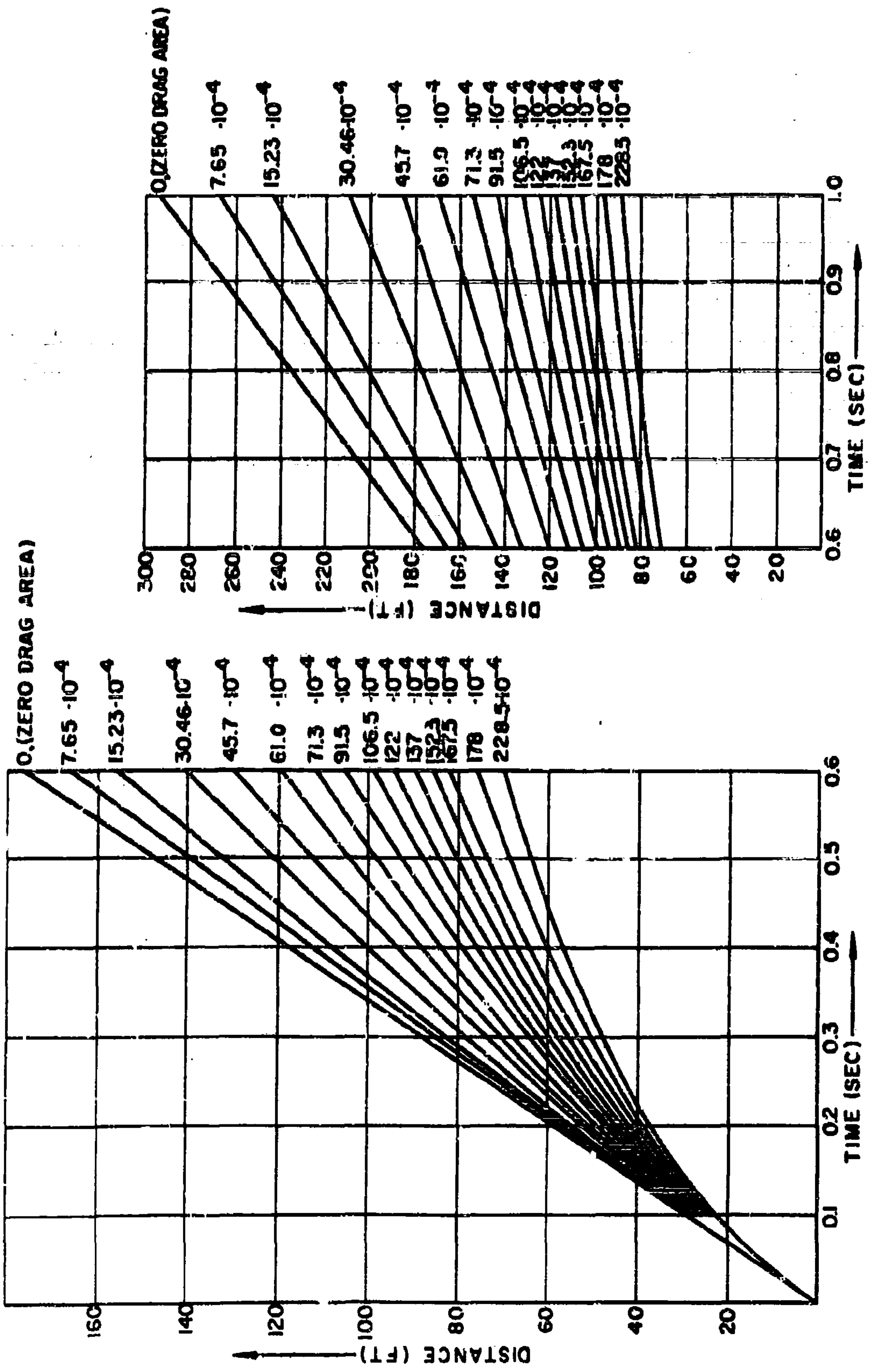

Figure 4-1-12. Distance of Travel of Bodies with Various Drag Loadings, Launched at 175 Knots

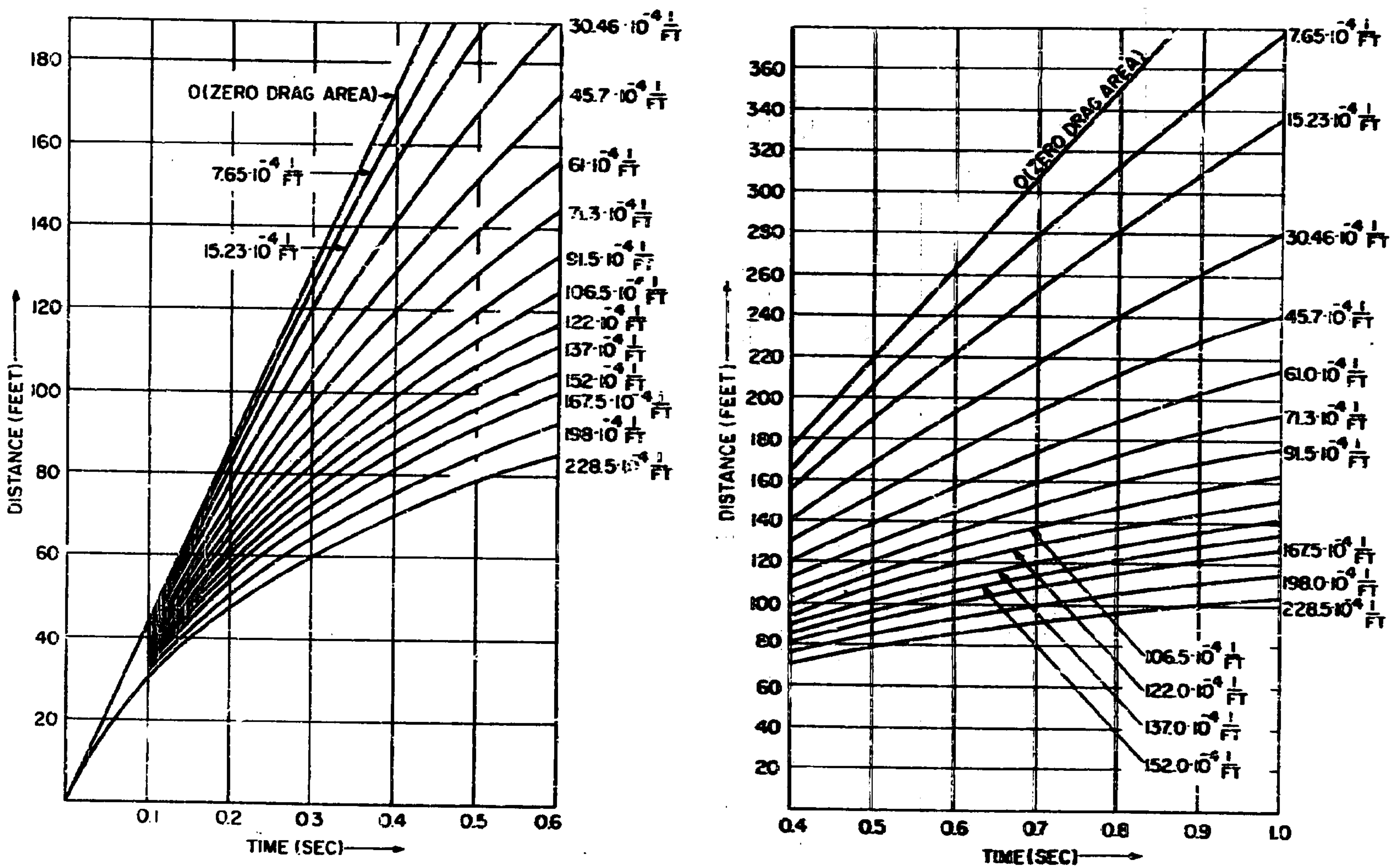

Figure 4-1-13. Distance of Travel of Bodies with Various Drag Loadings, Launched at 260 Knots

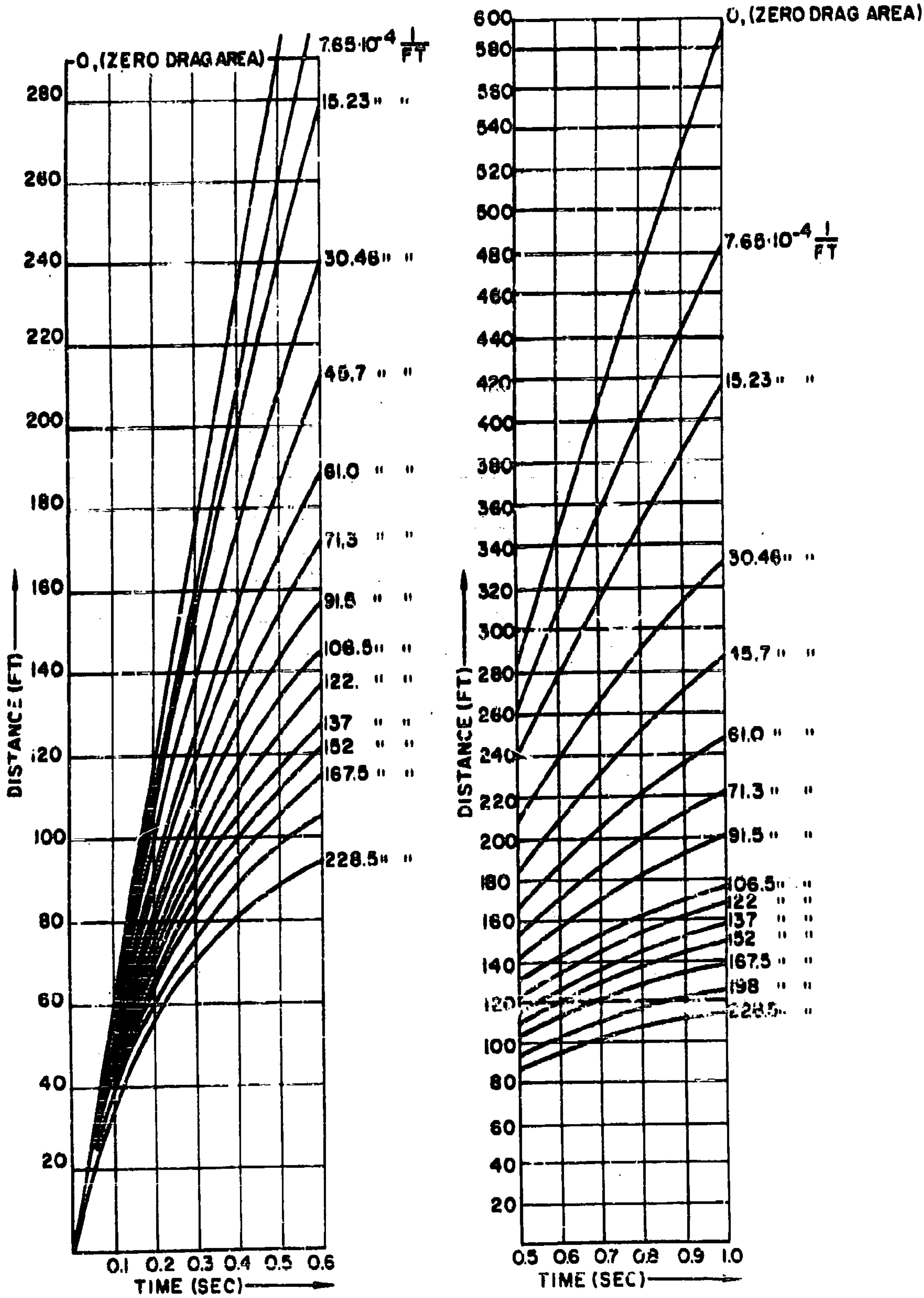

Figure 4-1-14. Distance of Travel of Bodies with Various Drag Loadings, Launched at 350 Knots

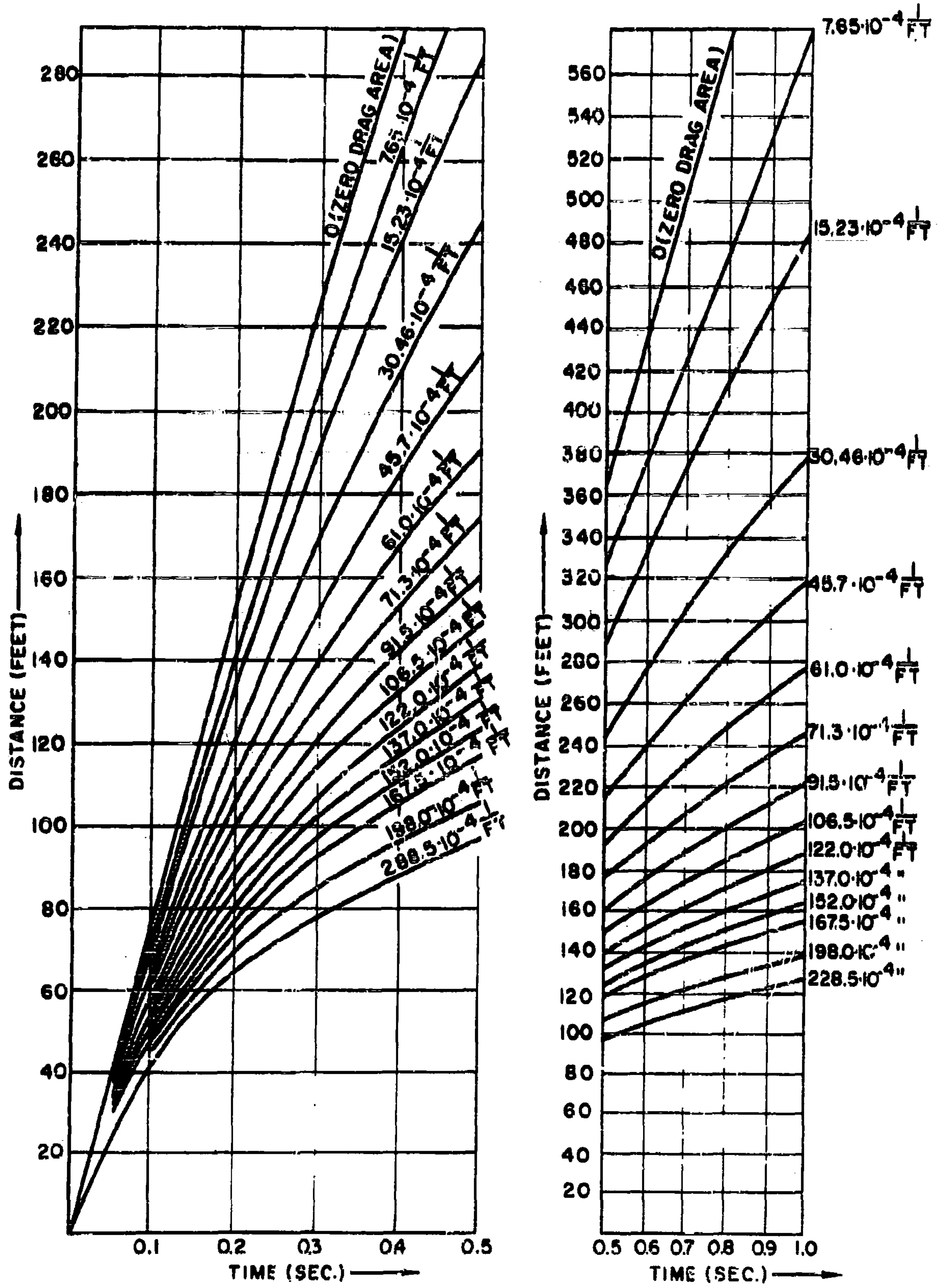

Figure 4-1-15. Distance of Travel of Bodies with Various Drag Loadings, Launched at 435 Knots

CHAPTER IV

SECTION 2

OPENING SHOCK OF PARACHUTE CANOPIES

2.1 GENERAL.

Determination of the opening shock of parachute canopies by mathematical processes, based upon an analysis of the physical processes of opening, has not been solved to any satisfactory degree. Based on a simplified theory, calculation of opening shock values can be accomplished. Comparison with actual test data has shown satisfactory agreement.

2.2 CONSIDERATIONS.

2.2.1 Under normal conditions, the opening shock of a parachute canopy depends upon:

a. Canopy diameter and drag coefficient.
b. The suspended load.
c. Launching speed or, more accurately, the speed at which the canopy begins to inflate.
d. Altitude of inflation.
e. Filling time of the canopy.
f. Increase of drag area from the moment of complete stretch of the suspension lines to full inflation of the canopy.

2.2.2 The current method of determining opening shock consists of a mathematical system that is exact if proper assumptions are made concerning filling time and increase of drag area versus filling time. Tests have shown that a relation exists, and can be determined, between opening time and diameter, velocity, and altitude; and that another relation, between drag-area increase and filling time, is discernible.

2.2.3 The system outlined has been applied mostly to ribbon canopies, but can also be applied to other types of canopies. Comparatively little test data are available for high-altitude parachute operation, but they indicate a relation between decrease of filling time and increase in altitude up to a certain altitude. This factor appears to be the major cause of the large increase in opening shock within this altitude range.

2.3 CALCULATION OF OPENING SHOCK.

2.3.1 The various stages of the opening process are shown in Figure 4-2-1, together with terms used in calculation of opening shock.

2.3.2 The equations of motion for the opening process can be written if D_o, C_{D_o}, W_t, ρ, g, V_s, and t_f are known, and if assumption can be made for the increase in drag area versus filling time.

2.3.3 If F_o is used to denote the actual opening force between parachute and suspended load, and F_c the force obtained with a constant velocity on the fully inflated parachute, expressed as

$$F_c = C_{D_o} S_o q_s$$

and if x denotes the relationship between actual opening shock F_o and the constant force F_c, expressed as

$$x = \frac{F_o}{F_c}$$

then the actual opening shock

$$F_o = C_{D_o} S_o q_s x K$$

where x and K are dimensionless factors for various types of parachutes.

2.3.4 In most cases, velocity V_s differs greatly from launching speed V_o. V_s can be determined by the formula

$$V_s = \frac{V_o}{1 + \frac{(C_D S)_B \rho g t_d V_o}{2W_t}}$$

where

$(C_D S)_B$ = drag area of the body, missile, or container, sq. ft.

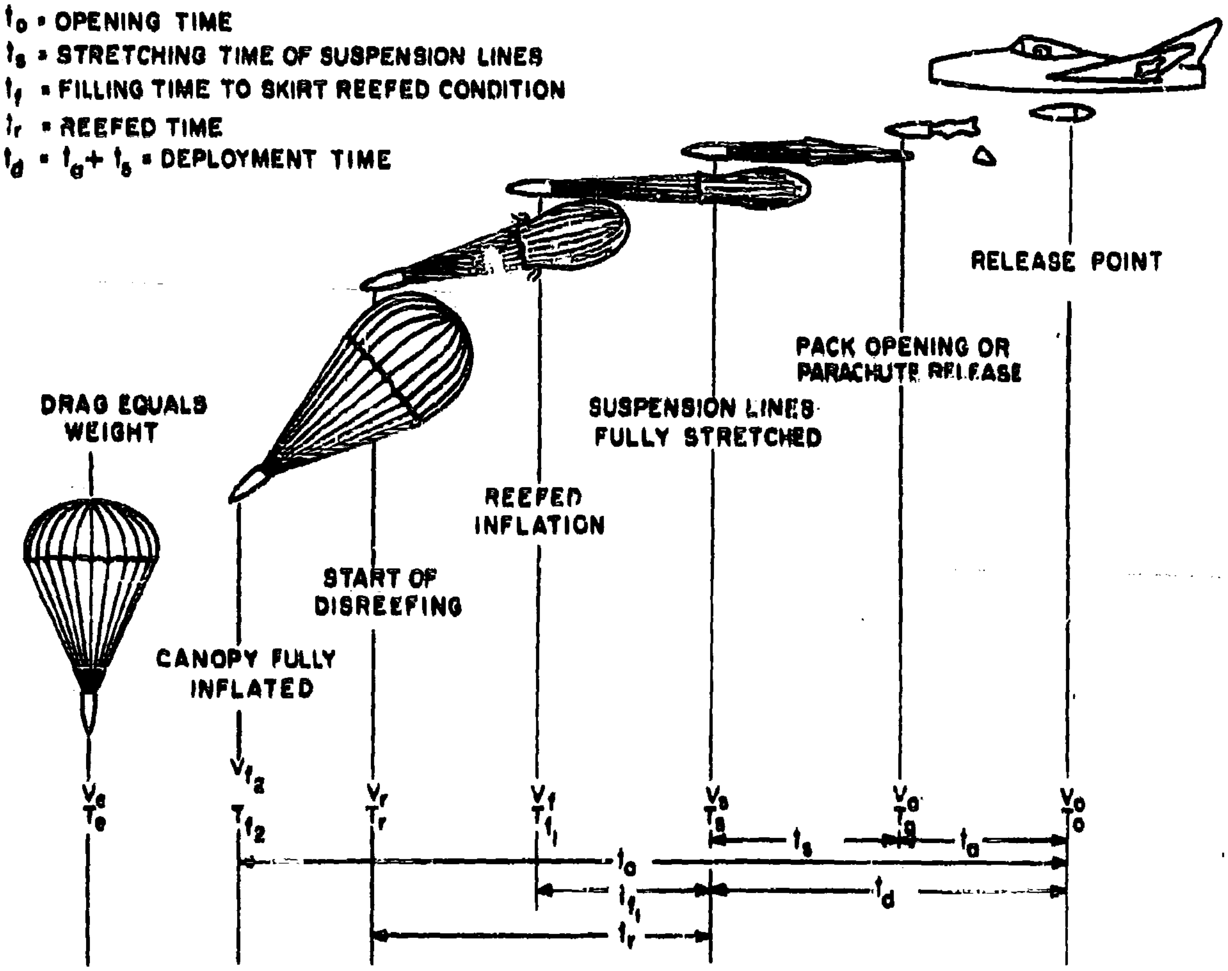

Figure 4-2-1. Process of Parachute Opening

t_d = deployment time, sec. (See Figure 4-2-1.)

This formula is usable for horizontal launching, so long as the ratio of horizontal speed to vertical speed is not smaller than two or three to one (usually, within 3 to 4 seconds maximum after launching).

2.3.5 From subsonic tests with practically infinite load and no velocity decreases during filling time (wind tunnel tests, aircraft deceleration, and other drops with a very high force to drag area ratio), xK factors have been measured. These xK factors should not be used for opening shock calculation unless the load approaches the infinite.

a. Solid flat parachute canopy xK = 2.0 (approx.)
b. Guide surface parachute canopy
   Ribless xK = 1.3
   Stabilization xK = 1.1
c. Ribbon and ring slot parachute canopy xK = 1.05
d. Rotofoil parachute canopy xK = 0.9

For infinite load conditions, the xK factor is a constant for a specific parachute canopy type, even during higher altitude deployment. Some variation in xK factor may be expected due to change in Mach Number.

2.3.6 FILLING TIME.

2.3.6.1 The following method of calculating filling time of a parachute canopy is suggested

for bodies requiring an equilibrium velocity of approximately 100 ft. per second or less.

2.3.6.2 Evaluation of motion pictures of drop tests shows that filling time is related to parachute diameter and launching speed, and, at least for normal loadings, it is somewhat related to the ratio of force to canopy drag area. An empirical formula to compute filling time value, based on present knowledge, is given below:

$$t_f = \frac{8\,D_o}{V_s^{0.9}} \frac{\rho}{\rho_o}$$

2.3.6.2.1 Filling times determined by this method agree substantially with values measured for ribbon canopies and agree reasonably with values for other types of canopies if a correction factor is later applied. However, it is preferable to use measured filling time data for the calculation of opening shock. Available information indicates that filling time decreases up to 40,000 feet, approximately with the ratio $\frac{\rho}{\rho_o}$. For very high velocities and very high altitudes, no test values are as yet available. It is expected that at very high velocities the filling time may decrease with altitude more slowly than the ratio would indicate, because of the mass and the relative rigidity of the parachute system.

2.3.6.2.2 The filling time of parachute canopies can be changed by various means, such as skirt hesitation, reefing, pocket bands, and deployment bags.

2.3.7 INCREASE OF DRAG AREA VERSUS FILLING TIME.

2.3.7.1 It is possible for the value of opening shock to be less than the theoretical steady drag at start of inflation, but not less than the instantaneous drag value at complete inflation. This latter value depends on the change of velocity during filling time, and actually becomes the opening shock force for a theoretical shockless parachute. In order to calculate an encompassing value for x, under conditions other than infinite load, a decreasing factor x can be obtained from Figure 4-2-2. In this figure, the decreasing factor x is plotted as a function of a dimensionless factor A. Evaluations of canopy opening processes have shown that the drag area of parachute canopies increases approximately linearly with filling time. Based on this assumption, a dimensionless factor A can be determined to approximate the velocity decrease during filling time.

$$A = \frac{2W_t}{C_{D_o} S_o V_s \rho t_f g}$$

2.3.7.2 The K factor, which shows the relationship between various parachute canopy types, has the following value:

a. Solid flat parachute canopy: K = 1.4
b. Ribbon and ring slot parachute canopy: K = 1.0
c. Guide surface and rotofoil parachute canopy: Test data and records have not been sufficiently evaluated at this time. A K factor of approximately 1.0 can be assumed, based on a comparison of known x factors at infinite load.

2.3.7.3 The accuracy of opening shock calculations may be improved by evaluation of cinetheodolite or normal motion picture test coverage to determine actual filling time values. Forces, velocities, and filling process should be determined with regard to time.

2.4 EXAMPLE OF OPENING SHOCK CALCULATION.

2.4.1 If a man-carrying standard parachute canopy with a diameter D_o = 28 feet, a drag area $C_{D_o} S_o$ = 460 square feet, a suspended load W_t = 200 pounds, and a load drag area $(C_D S)_B$ = 4.5 square feet is launched at sea level at V_o = 250 knots, the following calculations should approximate the opening shock of the parachute.

2.4.2 For the time $t_a + t_s = t_d$ (Figure 4-2-1) we assume 0.7 second. The speed decrease from launching speed V_o to the velocity V_s is

$$V_s = \frac{V_o}{1 + \dfrac{(C_D S)_B \rho g t_d V_o}{2W_t}}$$

$$V_s = 337 \text{ ft. per sec.}$$

therefore

$$q_s = 136 \text{ lb. per sq. ft.}$$

2.4.3 The filling time can be determined from

$$t_f = \frac{8\,D_o}{V_s^{0.9}} \frac{\rho}{\rho_o} = \frac{(8)\,(28)}{337^{0.9}}\,(1) = 1.192 \text{ sec.}$$

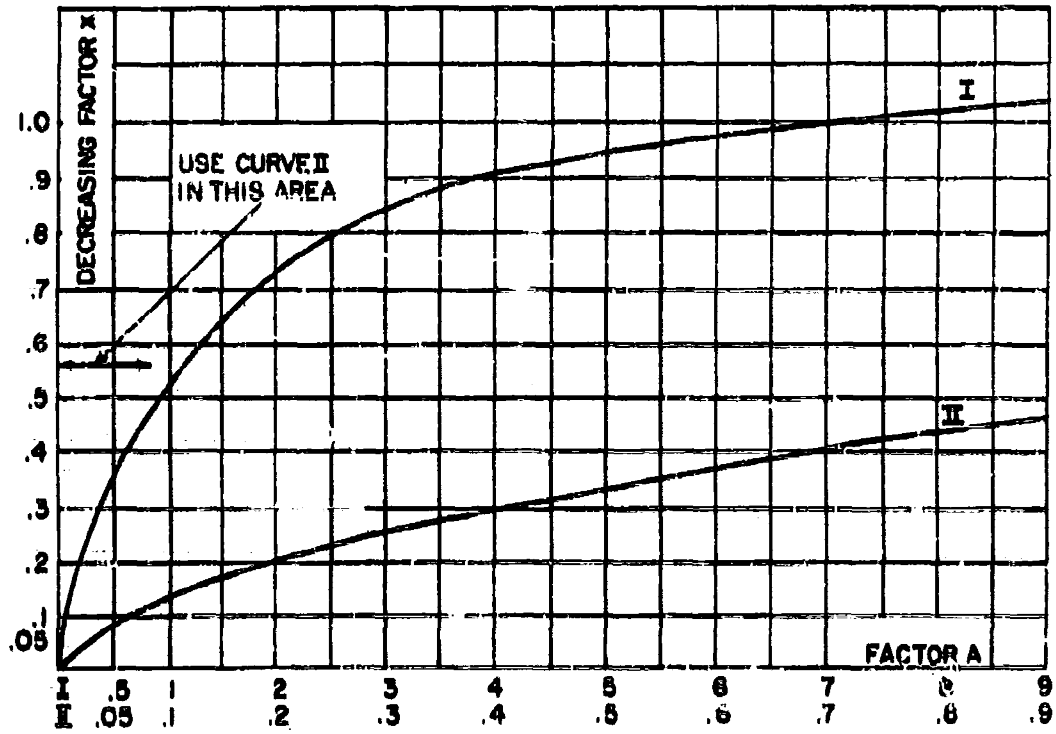

Figure 4-2-2. Opening Shock Decreasing Factor x Versus Factor A

2.4.4 Factor A remains to be determined

$$A = \frac{2W_t}{C_{D_o} S_o V_s \rho t_f g}$$

$$A = 0.0283$$

2.4.5 The decreasing factor, therefore, is in accordance with Figure 4-2-2: x = 0.067.

2.4.6 Opening shock, therefore, is equal to

$$F_o = C_{D_o} S_o q_s x K$$

$$F_o = (400)\ (136)(0.067)(1.4)$$

$$F_o = 4{,}990 \text{ lb.}$$

2.5 COMPARATIVE CALCULATIONS.

2.5.1 In Figure 4-2-3 are shown the results of calculations covering various parachutes for velocity V_o, filling time t_f, and altitude. In examples 1, 2, 3, and 5, normal filling times are assumed. In 4, 6, and 7, longer filling times are established to show the decrease in opening shock. In examples 1 and 5, the launching speed is equal to the free-fall velocity of the suspended load. Thus, there is no decrease in velocity from launching to point t_s.

No.	D_o	Altitude (ft)	V_o (knots)	$t_a + t_s$ (sec.)	V_s (knots)	t_f (sec.)	x	F_o (lb)	Decel (g)	Remarks
1	28	0	115	--	115	1,76	0,072	1,660	8,3	Terminal speed
2	28	0	260	0,7	204	1,16	0,064	4,860	24,3	
3	28	0	260	1,0	186	1,25	0,062	3,960	19,8	Filling time increased
4	28	0	260	0,7	204	2,5	0,038	2,870	14,3	
5	24	40,000	208	1,0	208	0,24	0,44	6,240	31,2	Terminal speed
6	24	40,000	208	1,0	208	1,0	0,21	2,980	14,9	Filling time increased
7	24	40,000	208	1,0	208	2.0	0,143	2,030	10,2	

Figure 4-2-3. Comparative Calculations

CHAPTER IV

SECTION 3

RATE OF DESCENT

3.1 CALCULATION OF RATE OF DESCENT.

In the following calculations, the rate of descent of a parachute is defined as a velocity at which the drag of the parachute canopy is equal to the total weight W_t (suspended load plus weight of the parachute system). This velocity is also called equilibrium velocity V_e.

For sea level conditions

$$V_{e_o} = \frac{2\sqrt{\frac{2}{\pi\rho_o}}}{D_e}\sqrt{\frac{W_t}{C_{D_o}}} = \frac{K}{D_o}\sqrt{\frac{W_t}{C_{D_o}}}$$

$$= \frac{32.724}{D_o}\sqrt{\frac{W_t}{C_{D_o}}}$$

wherein V_{e_o} equals the equilibrium velocity at sea level.

For any given altitude the equilibrium velocity is a function of density and gravity, and, at higher speeds also a function of Mach number. Thus

$$V_e = V_{e_o}\sqrt{\frac{\epsilon}{\sigma}}$$

wherein $\epsilon = \frac{g}{g_o}$

$\sigma = \frac{\rho}{\rho_o}$

Graphs showing the relationship between $\sqrt{\epsilon}$ and $\sqrt{\sigma}$ and altitude are presented in Figures 4-3-1 and 4-3-2.

3.2 GENERAL INFORMATION.

A majority of parachute canopies are designed as geometric shapes which differ from the inflated shape of the canopy; the exception being the Guide Surface Type canopies which are essentially designed to the inflated shape. For this reason, it is more practical to relate the drag coefficient to a constructed shape or area in all cases except for the Guide Surface Type canopies. In the case of the Guide Surface Type parachute canopies, C_D is based upon the inflated or designed maximum diameter.

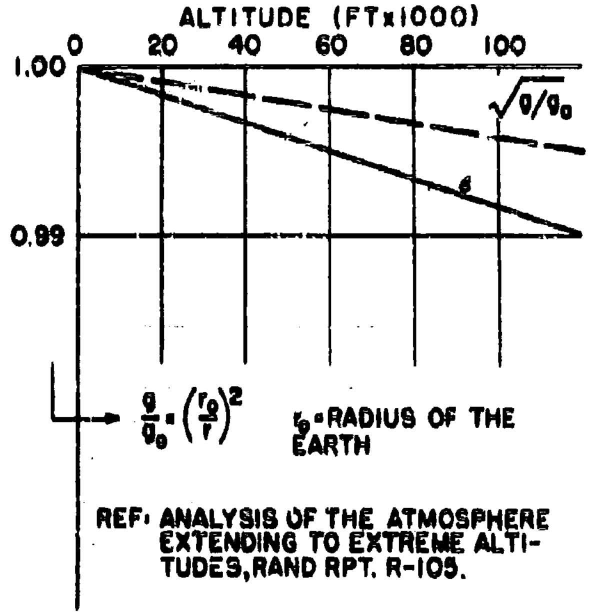

Figure 4-3-1. Gravity Ratios

3.3 DRAG COEFFICIENTS.

Parachute canopy diameter versus total load, i.e. suspended load plus weight of the parachute system, for various rates of descent and drag coefficients is presented in Figure 4-3-3. This graph is presented for sea level conditions. For other altitudes these values should be modified by multiplying with $\frac{1}{\sqrt{\sigma}}$. Values for $\frac{1}{\sqrt{\sigma}}$ can be obtained from Figure 4-3-2.

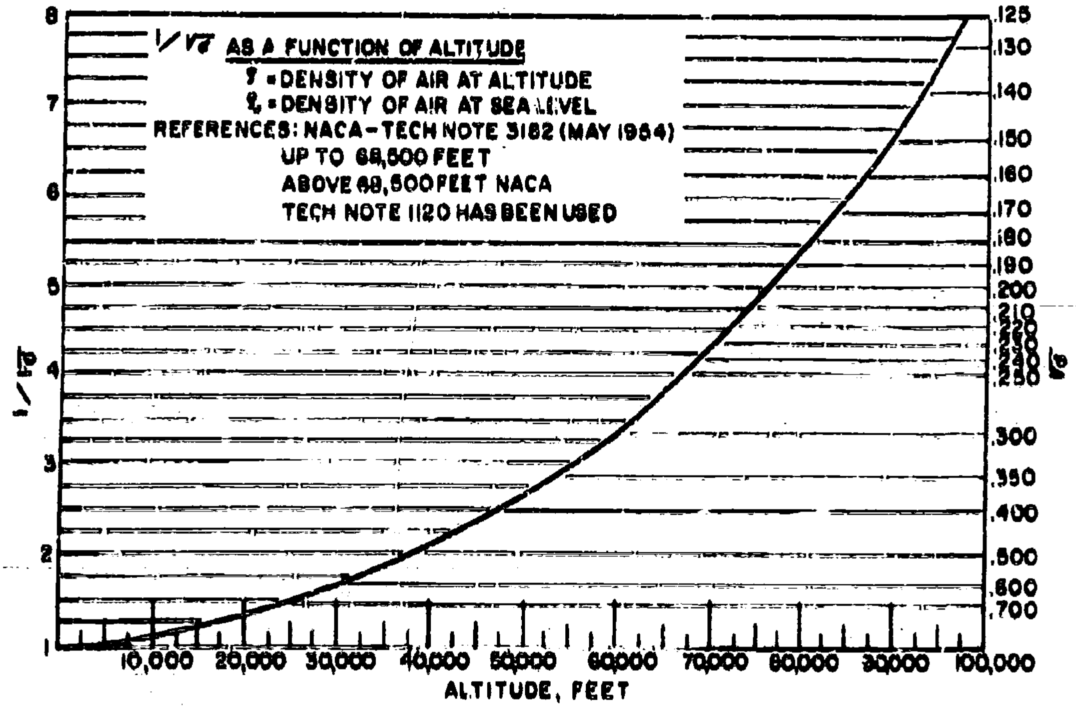

Figure 4-3-2. Pressure Ratios

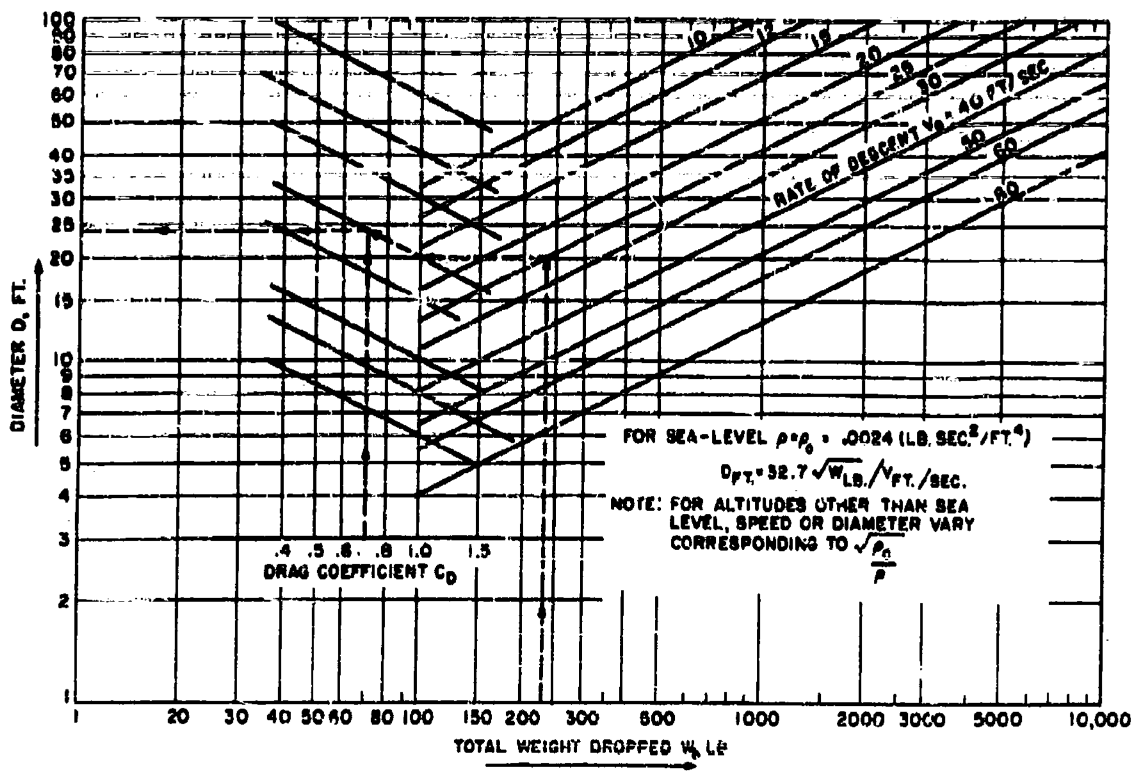

Figure 4-3-3. Diameter Required as a Function of Total Weight Dropped and of the Rate of Descent

CHAPTER IV

SECTION 4

PRESSURE AND STRESSES ON A PARACHUTE CANOPY

4.1 GENERAL.

The importance of knowing stress distribution in parachute canopies and its relation to canopy strength lies in the necessity for minimizing weight. In light weight design, where strength is a factor, stress analysis is an indispensable element. The stresses in a parachute canopy are caused by aerodynamic loads acting on various structural components and being transferred between them. Stresses in a parachute canopy are both dynamic and static. Dynamic stresses exist for a comparatively short time, namely, during the transition period between the time the canopy is released into the airstream and the time a steady state is reached. Although the stresses are not constant during the steady state, their variation is small in comparison with those encountered during the transition period, and they can be considered as static.

4.1.1 As the canopy starts to inflate, the air flow into and around the canopy causes a rapidly changing pressure distribution, which in turn causes the canopy to change shape. Consequently, stress distribution and magnitude also change rapidly with the shape and load. Because of variations in the opening forces of the canopy, the factors affecting stresses tend to vary, even for "identical" conditions.

4.1.2 Knowledge of three basic items is required to conduct a stress analysis: the characteristics of the structural material, the shape and fabrication of the structure, and the magnitude and manner of application of the load. In a canopy, the load-carrying members are primarily of fabric, which has no stiffness and, therefore, can take no bending loads. Loads are resisted by tension in the fabric members. Many types of fabric are utilized, each having its own load-carrying characteristics. The shape and construction vary with the type of parachute canopy. The canopy, which may be of solid or grid construction, is the drag-producing element. The canopy load is transferred into the suspension line system by way of the main seams and ribs. Stress analysis is extremely complicated, since maximum stresses occur during the opening process, which is the period of rapidly changing shape and load. At present, the only workable solution to stress determination in a parachute canopy involves correlation of the commonly measured variables into empirical solutions.

4.2 STRUCTURE ANALYSIS.

4.2.1 BASIC ASSUMPTIONS. As mentioned heretofore, the load-carrying element of a parachute canopy is a material unable to take bending loads because it has no stiffness. Consequently, loads can be resisted only by tensions in the curved members. There remain, then, three basic groups of variables: stress, shape, and loading. Presently, parachute canopy design is based on selecting a known loading condition and then inferring the shape from the opening and descent characteristics desired. Based on these assumptions, the stresses involved may then be solved. Theoretically, the canopy may be considered to be a thin flexible shell acted on by normal and tangential forces. To apply the equilibrium equations of a small section of this shell, certain other assumptions need to be made, the use of which removes the problem and its solution from the practical to the classical. These assumptions are:

a. The surface is formed by rotating a curve about a straight axis.
b. The aerodynamic forces are rotationally symmetrical.
c. The material is inextensible.

4.2.1.1 On equating the forces acting on a small section of a shell in equilibrium (Figure 4-4-1), the equations of the well-known diaphragm tension theory, or theory of a thin flexible shell, are obtained.

4.2.1.2 A special solution results in the well-known Taylor shape. If there are a large number of lines over the canopy, an equal number of radial crinkles results and a shape is produced in which the circumferential stress is zero. This shape is just on the verge of collapse and is the flattest shape possible. Pressure distribution on the Taylor shape is approximately constant. See Figure 4-4-2.

4.2.1.3 In the foregoing analytical solutions, many assumptions were needed to make the solution possible or simplify it to a point where it could readily be adapted for use. However, many of these assumptions about loading, shape, and stresses were not very realistic. It is important to know how these assumptions fare in actual operation.

4.2.2 PRESSURE. A common assumption is that pressure is uniformly distributed over the surface. Comparison of the pressure distribution at three velocities on unvented models is shown in Figure 4-4-3. The curve shape is generally the same in the upper portion of the canopy, but decreases in magnitude with an increase in velocity. At the highest velocity (130 feet per second), the pressure at the skirt increases rapidly.

4.2.2.1 When geometric porosity is added, the pressure in the upper portion decreases and becomes irregular, while the pressure drops off on the lower portion of the canopy. With the porosity increased still more, the above effects are increased. The decreased pressure at the skirt indicates that the squidding velocity is being approached, since squidding velocity decreases with increased porosity.

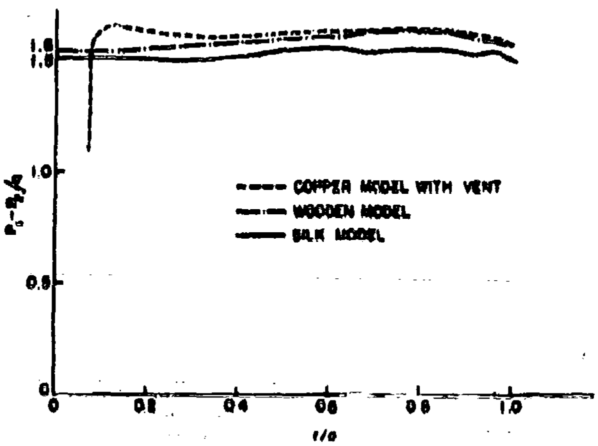

Figure 4-4-2. Pressure Distribution over Several Taylor-Shaped Models of 8-Inch Diameter

4.2.2.2 The squidding phenomenon is better demonstrated by Figure 4-4-4, which represents tests on free fabric models. Squidding occurs when the pressure at the skirt acts inward, causing a collapse of the skirt. When the canopy is operating well below the squidding velocity, the pressure is more or less constant over the canopy. As the squidding velocity is approached by either increasing the velocity or decreasing the suspension line length, the pressure at the skirt approaches zero.

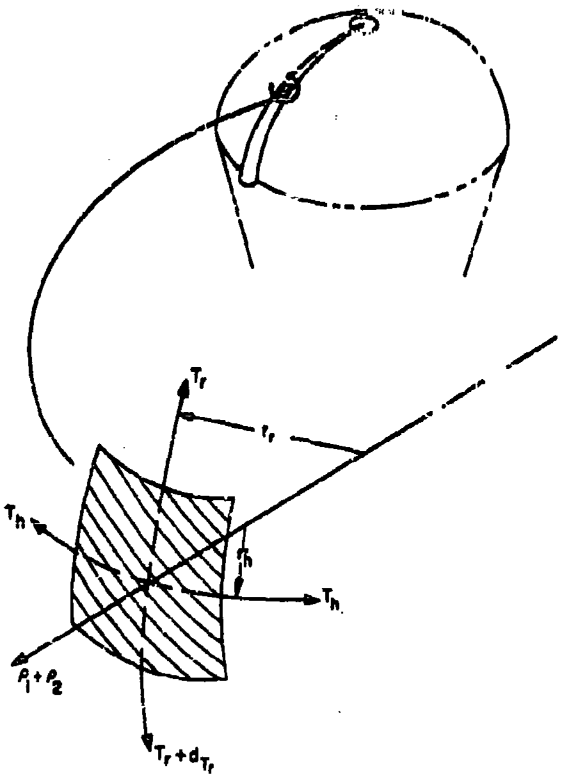

Figure 4-4-1. Forces Action on a Small Segment of a Flexible Shell in Equilibirum

4.2.3 DRAG. Even when pressure distribution is known, it must still be related to drag. If the drag is composed only of the axial component of the pressure force, the drag will be

$$D = 2\pi \int_{r_{min}}^{r_{max}} p r_c \, dr_c$$

which, when p equals constant, is equal to pS_p. This is the form most generally used, because the pressure differential p is readily determined if the drag is known. However, this expression does not take into consideration the effect of skin friction and the eddies around the mouth. Tests on porous fabrics and ribbon grids have shown fair agreement with calculated values, especially with the ribbon grids. The drag coefficient of the fabric, however, is somewhat higher in the higher porosity ranges.

4.2.4 SHAPE. The next general assumption used is that the canopy surface is a surface of

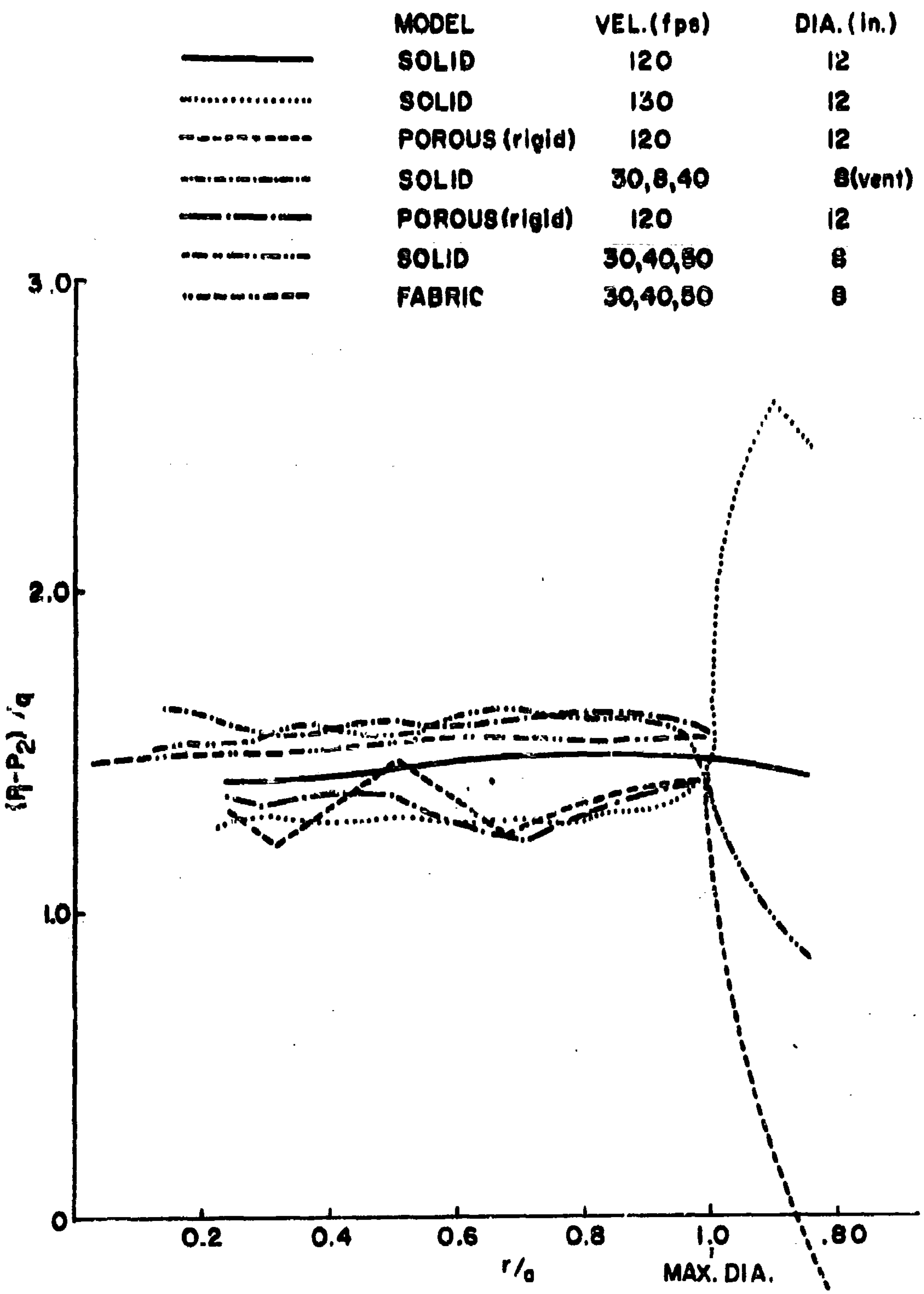

Figure 4-4-3. Pressure Distribution over Taylor-Shaped Models

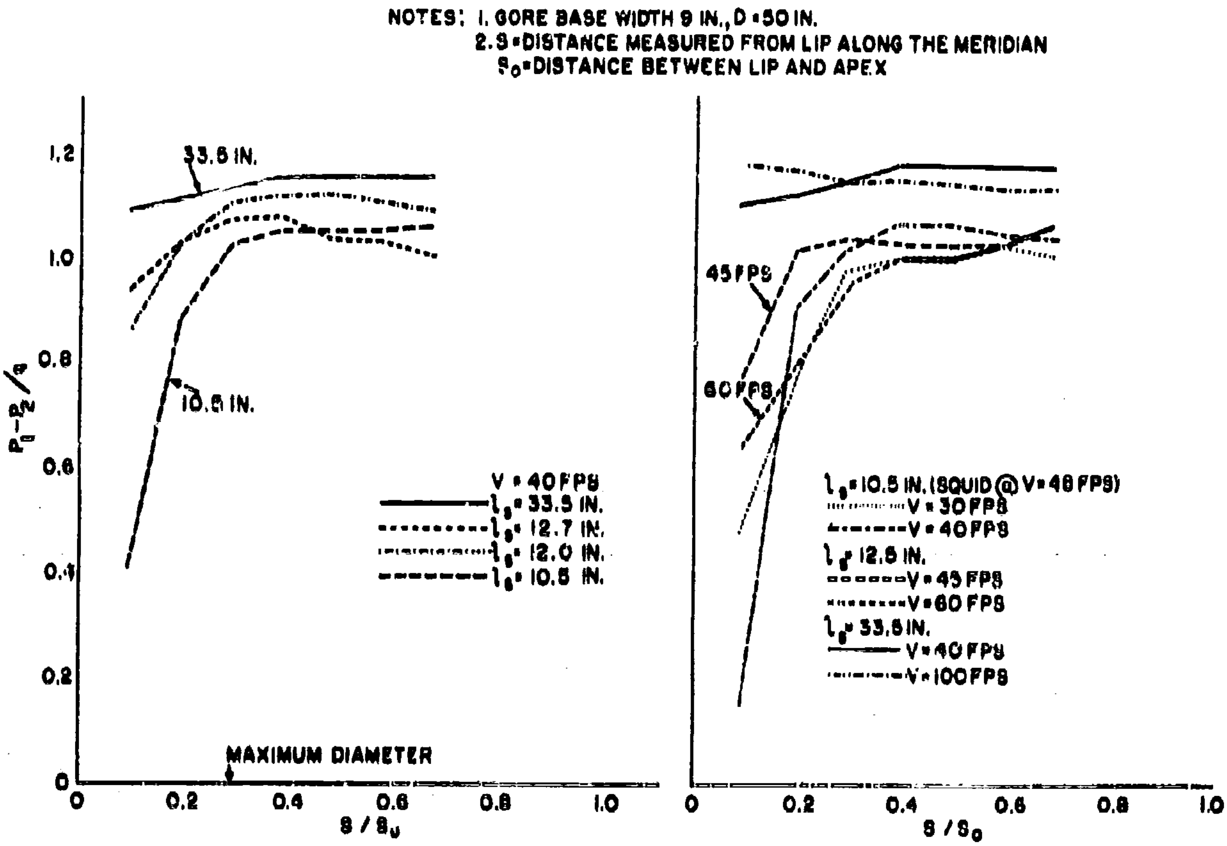

Figure 4-4-4. Pressure Distribution over Surface of Free Fabric Model of Taylor Shape as Affected by the Change of Velocity and Suspension Line Length

revolution. For this to be realized, the load from the suspension lines must be transferred uniformly into the skirt. However, this requires a unique suspension line system. Because of bulk and complexity, this assumption generally is not considered a satisfactory solution. In all of the other types, the load is transferred into the skirt at uniformly spaced points, which causes an outward fullness between the main radial seams. In the case of a surface of revolution of known shape, both radii of curvature are known over the entire surface. When there is a fullness in the gores, both radii are changing over the entire gore. Theories considering fullness have been developed. One theory is based on a constant radial stress and zero circumferential stress. The surface of the gore is generated by a circle of constant radius, and it is assumed that the suspension lines take up the Taylor shape. The circle lies in the plane containing the normals to the pair of lines at points equidistant from the apex. Theoretically, there is no transference of load from the canopy to the suspension lines at the attachment points and the longitudinal stress in the canopy is reduced to a minimum.

4.2.5 MATERIAL. Another assumption generally made is that the material is inextensible. In many cases where the fabric is nearly flat, as in the case of the vent area in the Taylor shape, the tensions have to be very high to support a load, as is seen by the equation

$$p = \frac{T_r}{r_r} + \frac{T_h}{r_n}$$

4.2.5.1 An extension of the fabric under load, considering the edges fixed (that is, a constant projected area), would tend to increase the curvature, and this in turn would decrease the tension.

4.2.5.2 Still another problem is determining how the canopy fabric resists the applied load. In assuming a flexible shell, the material is generally thought of as a homogeneous material, such as metal. However, fabric is not homogeneous but is a grid of warp and fill yarns. If the load is applied along the direction of the yarns, either uniaxially or biaxially, the grid pattern remains undeformed except for the elongations, but if a uniaxial load is applied at an angle to either yarn direction, a deformation of pattern occurs. When the fabric is considered to be a homogeneous material, the loads are broken up into components acting along the undeformed yards. But since there is some deformation, the loads must be divided between the warp and fill yarns.

4.2.6 EMPIRICAL APPROACHES. In the previous description of analytical solutions, various assumptions were made to simplify the stress problem. The solutions have been limited to a steady state condition in which some of the assumptions are more or less justified. Still, the shapes and loading are not very well known for the various types of parachute canopies for steady state descent. Even less is known about them during the transition period between release into the airstream and steady-state descent. Attempts are being made at the present time to solve these problems.

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CHAPTER IV

SECTION 5

PARACHUTE CANOPY REEFING SYSTEMS

5.1 GENERAL.

Canopy reefing is a term used to describe a method by which the projected diameter of a parachute canopy is reduced temporarily, resulting in a reduction of the drag area of the canopy.

5.2 APPLICATIONS.

Reefing may be applied to the following operations:

a. Limitation of canopy opening force to a predetermined value through opening at predetermined intervals, called disreefing, or through controlled continuous disreefing.
b. Attainment of a temporary high rate of descent by strong reefing to achieve accurate drops from high altitudes.
c. Achievement of a temporary low-drag area with large landing brake parachutes for planes and gliders. Reefing also allows such parachutes to be used as dive and gliding angle brake parachutes. After leveling off, the parachute canopy is disreefed and becomes a powerful landing brake.
d. Use of parachutes as dive brakes, which can be retracted and extended in flight by means of reefing methods.
e. Increasing the stability of a parachute canopy, either temporarily for a particular application, or to adapt an available parachute to an application that requires increased stability.

5.3 REEFING METHODS.

5.3.1 SYSTEM I. Figure 4-5-1 shows skirt reefing System I. A line, called the reefing line, passes around the skirt of the canopy through reefing rings located on the skirt at each suspension line. The reefing line is fastened at both ends and is cut with a disreefing device after a certain delay period. At least two disreefing devices are recommended for reliability. Disreefing device M-2, shown in Figure 6-2-1, was developed for Air Material Command by Ordnance. Devices with time delays in increments of 2, 4, 6, 8, and 10 seconds are available. System I is recommended for purposes where the disreefing time is fixed, and is not longer than 10 sec.

5.3.2 SYSTEM II. For longer or variable periods, reefing System II, illustrated in Figure 4-5-2, is advisable. Any timing device that can actuate a cutting piston may be used to part the control line and disreef the canopy. This method is particularly adaptable to designs in which disreefing must be a function of several variables, and requires a large and complicated actuating device. Figures 4-5-3, 4-5-4, and 4-5-5 show details of reefing line and reefing cutter installation on an aerial delivery parachute canopy.

5.4 FORCES.

5.4.1 The reefing line must be designed to withstand variable forces, dependent upon the percent of drag area of the parachute canopy in the reefed condition compared with the drag area in the fully inflated condition.

5.4.2 Figure 4-5-6 shows the skirt opening force perpendicular to the axis of the parachute canopy, the force in the reefing line, and the force in the control line. All forces are plotted in percent of the total drag developed by the reefed canopy.

5.4.3 The reefing ratio is defined as the ratio of drag area of the reefed parachute canopy to the drag area of the fully inflated canopy. For example, a canopy reefed to 40 percent of its original drag area will develop in the reefing line a force of 2 percent of the total drag developed by the reefed parachute canopy. (See Figure 4-5-6.) The forces in the control lines were measured on a 10-foot diameter FIST ribbon parachute towed behind an aircraft at 105 knots. The forces in the reefing line and the skirt opening forces were calculated from the forces measured in the control line. The small amount of friction in the reefing rings

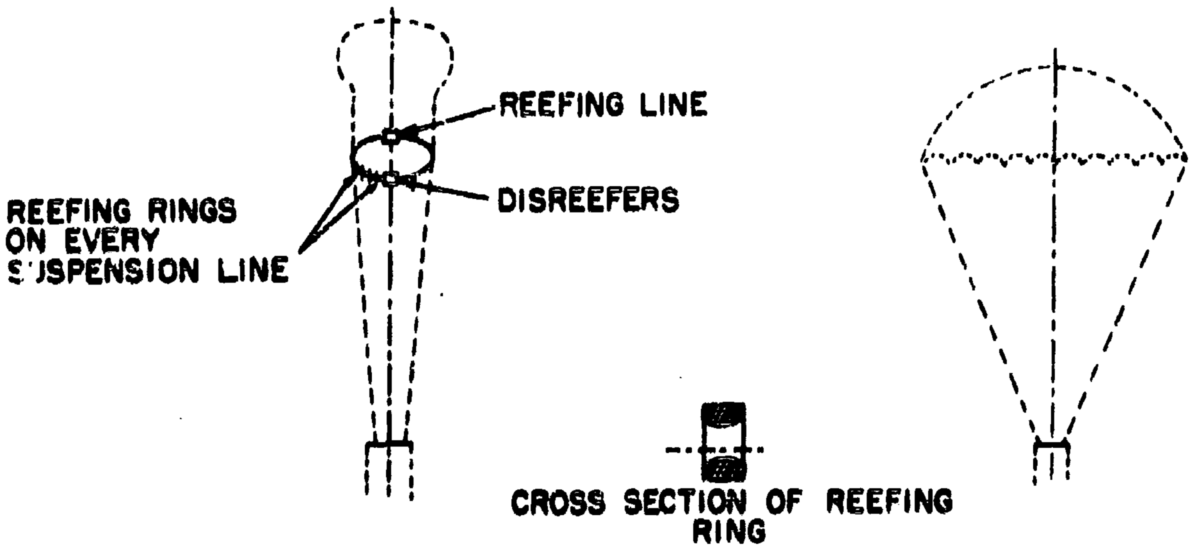


Figure 4-5-1. Canopy Skirt Reefing I

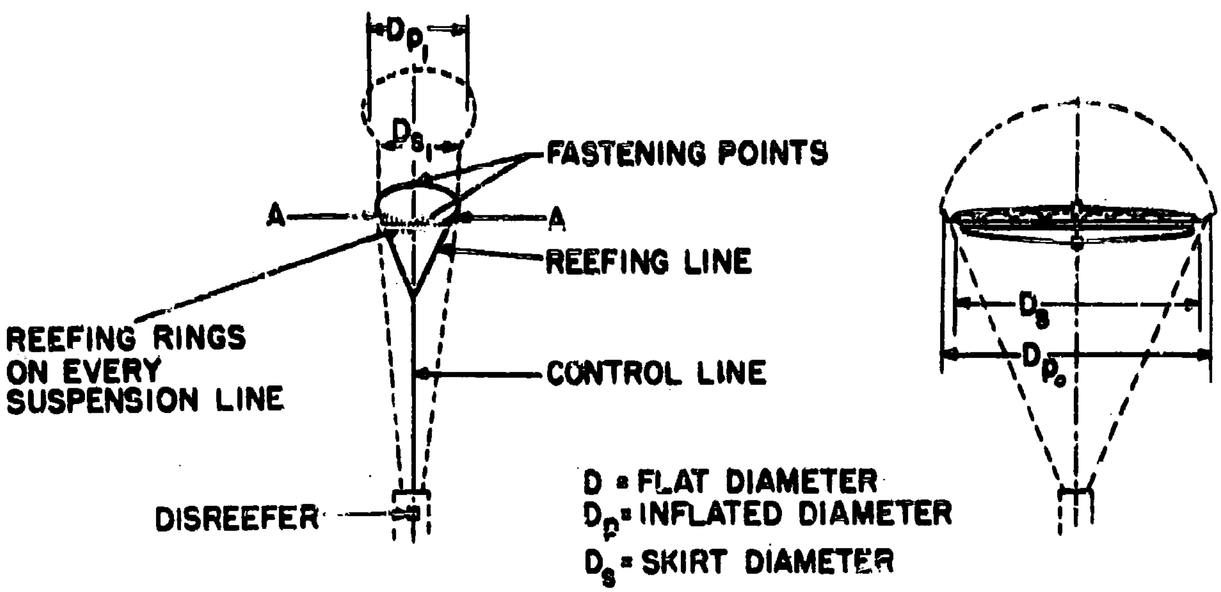


Figure 4-5-2. Canopy Skirt Reefing II with Control Line

has been neglected. Since reefing and control lines are exposed to high abrasion, a safety factor of 2.5 for reefing and control lines is recommended.

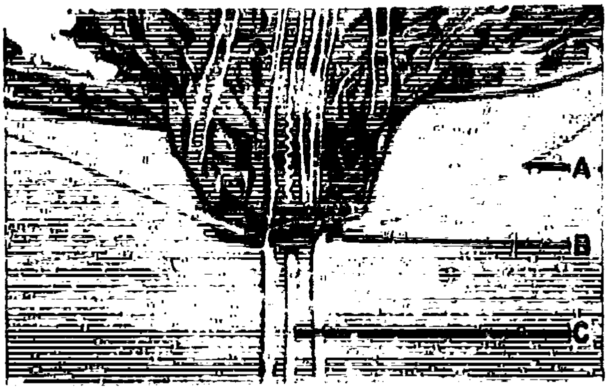
5.5 CALCULATIONS.

5.5.1 If the opening shock of the requisite parachute canopy is too high, or if a smaller drag area is needed temporarily, the diameter of a smaller canopy, whose drag area will not exceed the opening shock or the desired permissible drag area, must be calculated. The permissible diameter and drag area of a reefed canopy can be determined as the diameter of a reefing line, as in the following example:

C_{D_o} = drag coefficient based on flat canopy area

C_{D_p} = drag coefficient based on inflated canopy area

D_o = flat diameter of the unreefed parachute



A — Reefing Line
B — Reefing Rings
C — Suspension Line

The Photograph Above Shows Point A on Figure 4-5-2 for Reefing System II. Two Rings Are Used at This Point Only; All Remaining Suspension Lines Carry Single Rings Attached to the Skirt by Heavy Hand-Stitching or Reinforcing Webbing.

Figure 4-5-3. Attachment of Reefing Rings

D_{p_o} = inflated (projected) diameter of the unreefed parachute (0.66 D_o)

$(C_D S)_{p_o}$ = drag area of the unreefed parachute (based on C_{D_p})

D_1 = (theoretical) diameter of the reefed parachute

$$= \frac{2}{0.66}\sqrt{\frac{(C_D S)_{p_1}}{\pi C_{D_p}}}$$

$$= 2\sqrt{\frac{(C_D S)_{R}}{\pi C_{D_o}}}$$

D_{p_1} = inflated diameter of the reefed parachute

D_{R_1} = diameter of reefing line of the reefed parachute

D_{R_o} = diameter of the reefing line of the fully inflated parachute canopy

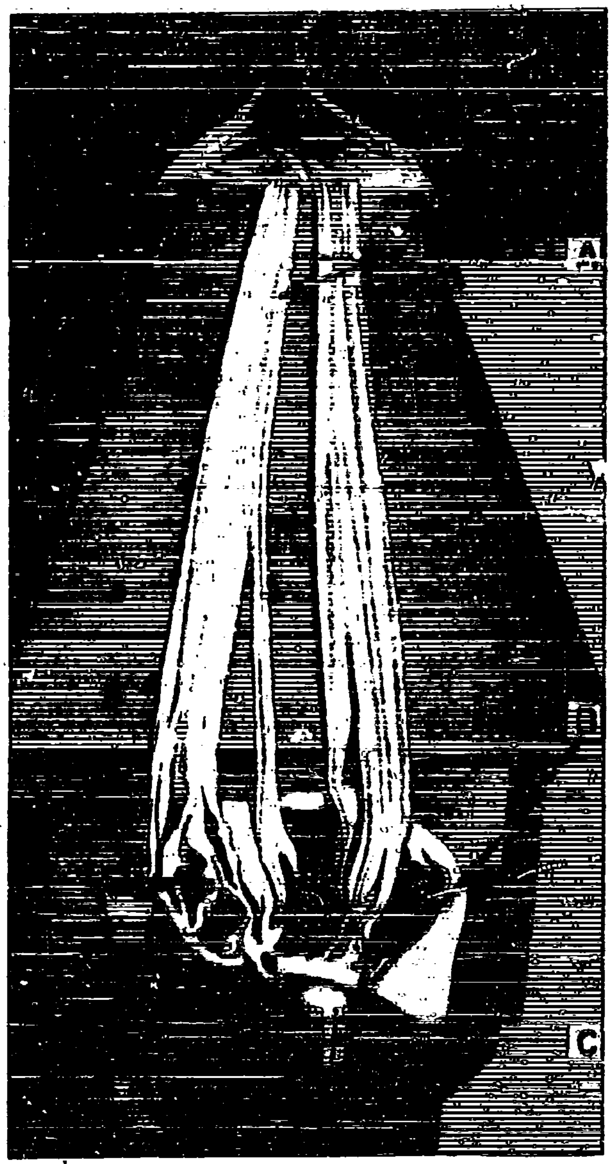
$(C_D S)_{p_1}$ = drag area of the reefed parachute

Z = number of gores or suspension lines

c = ratio of reefing line diameter to flat (constructed) canopy diameter = D_{R_o}/D_o

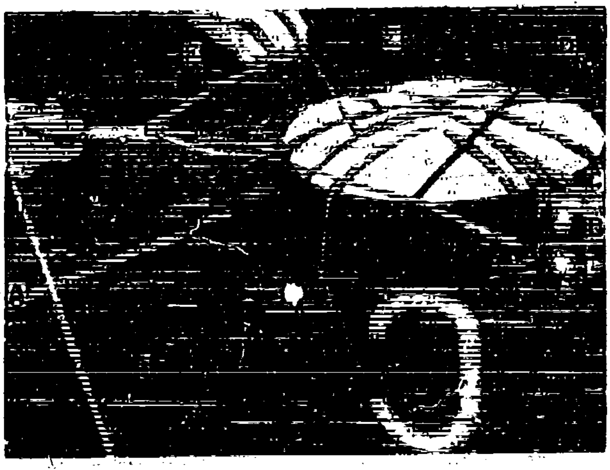
8 = ratio of reefing line diameter D_{R_1}/D_{R_o} to various drag area ratios $(C_D S)_{p_1}/(C_D S)_p$

5.5.1.1 If a parachute with a C_{D_o} = 1.05, of D_o = 20 ft., with Z = 20 Gores, and a drag area $(C_D S)_{p_o}$ = 148 sq. ft., has a permissible



A — Combined Reefing and Control Line
B — Replaceable Cut-Line
C — 60-Second Timer with Cutting Piston

Figure 4-5-4. Reefable Aerial Delivery Parachute Canopy With Reefing Cutter



A – Static Line to Aircraft, for Opening parachute Pack and Arming Reefing cutter
B – Reefing Cutter
C – Cut-Line
D – Reefing Cutter Arming Line
E – Static Line to Apex of Parachute Canopy
F – Static Line for Opening Parachute Pack

Figure 4-5-5. Packed Reefable Aerial Delivery Parachute and Container, with Reefing Cutter Assembly

drag area reefed $(C_DS)_{p_1}$ = 16 sq. ft., the drag area ratio then equals

$$\frac{(C_DS)_{p_1}}{(C_DS)_{p_o}} = \frac{16}{148} = 0.108$$

Therefore, for 20 Gores, c = 0.61. (See Figure 4-5-8.)

5.5.1.2 For a drag area ratio of 0.108, δ = 0.194. (See Figure 4-5-9.)

5.5.1.3 With this data, the diameter of the reefing-line circle may be determined:

$$D_{R_1} = D_o \delta$$

$$D_{R_1} = 20 \times 0.61 \times 0.194 = 2.36 \text{ ft.}$$

5.5.2 The theoretical and inflated diameter of the reefed parachute can also be calculated.

$$D_1 = \frac{2}{0.66} \sqrt{\frac{16}{1.05\pi}}$$

$$D_1 = 6.7 \text{ ft.}$$

$$D_{p_1} = 0.66\,D_1$$

$$D_{p_1} = 4.4 \text{ ft.}$$

The data in Figures 4-5-7, 4-5-8, and 4-5-9 have been tested and apply for all types of flat parachutes.

5.6 REEFING RINGS.

5.6.1 The use of flat cross section reefing rings, as shown in Figure 4-5-10, is very important, since the surface area presented prevents any hinging action in the ring, with

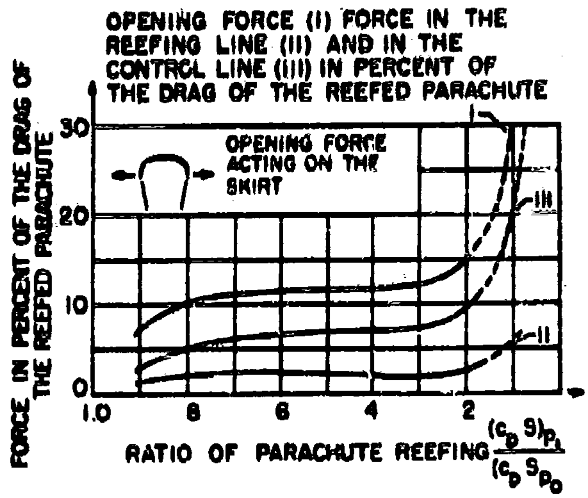


Figure 4-5-6. Skirt Reefing; Reefing Line, Control Line, and Skirt Opening Forces

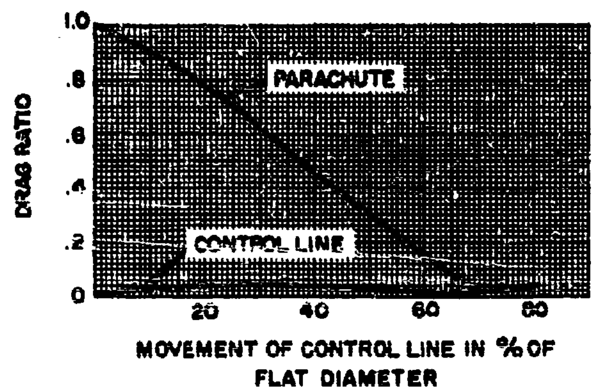


Figure 4-5-7. Relative Drag Versus Relative Control Line Setting

consequent binding of the reefing line between the ring and the skirt of the parachute. Use of round cross section reefing rings should be avoided, as failures may occur.

5.7 GENERAL DATA.

To prevent twisting, reefed parachute canopies should always be slightly inflated, since stability will be increased markedly. The diameter of the reefing line should thus be not less than 10 percent of the flat diameter for small parachute canopies, nor less than 5 percent of the flat diameter for larger parachute canopies.

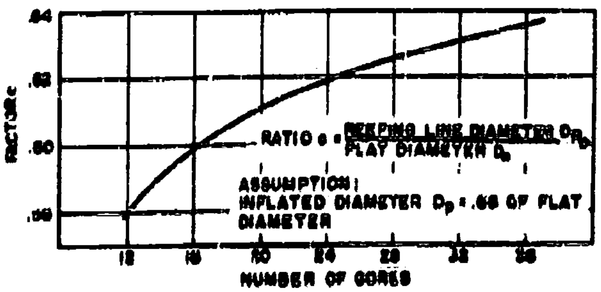


Figure 4-5-8. Ratio c Versus Number of Gores

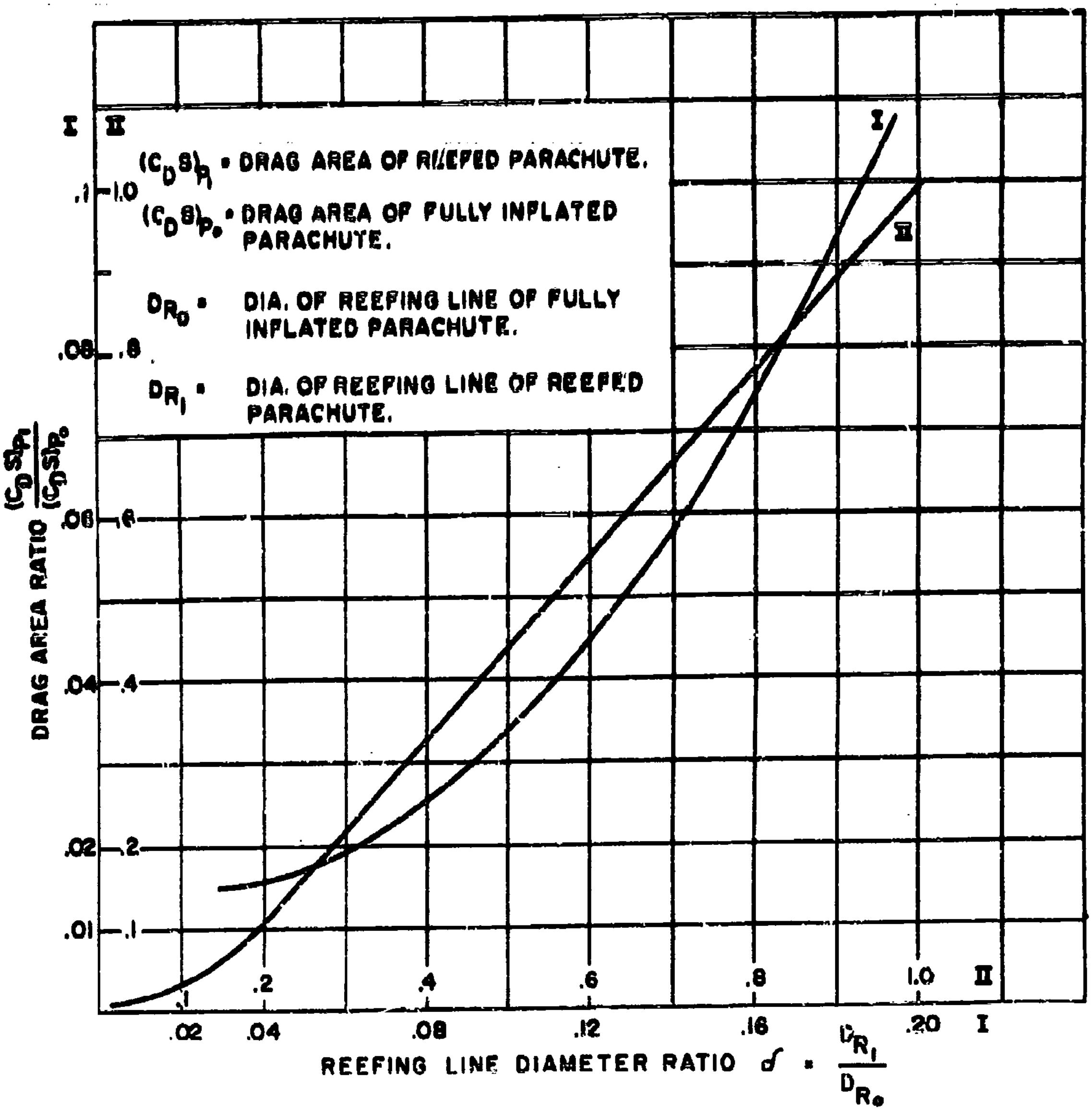


Figure 4-5-9. Drag Area Ratio Versus Reefing Line Diameter Ratio

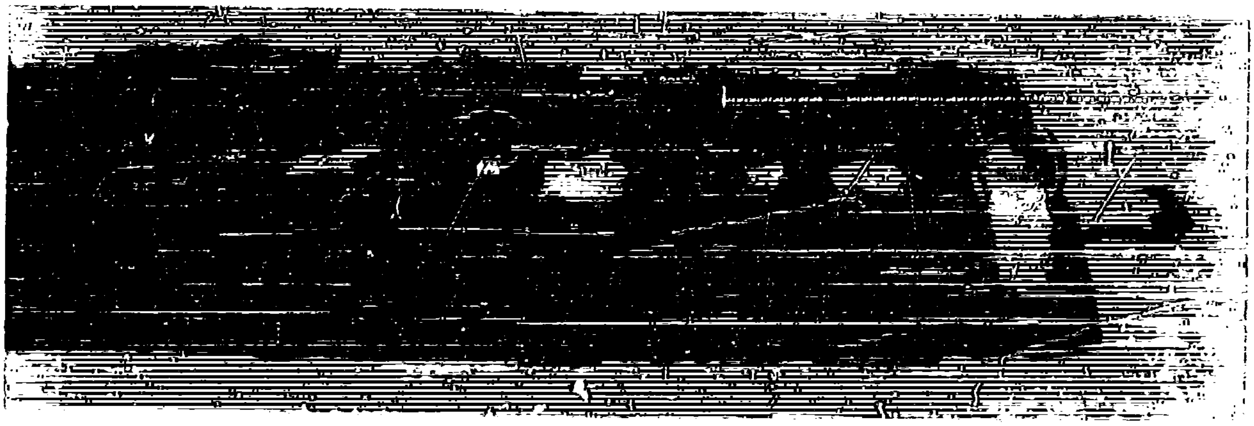


Figure 4-5-10. Attachment of Reefing Rings

CHAPTER V

PARACHUTE DESIGN AND CONSTRUCTION CHARACTERISTICS

The state of the art of parachute design has been advanced in recent years to the status in which sufficient recorded experience exists to enable the parachute designer to take an analytical approach to new design problems. However, the parachute performance parameters are extremely complex in detail and subject to conditions of application which, in the end, may be so random that the determination of the success with which the design is carried out usually becomes a matter for statistical evaluation over a considerable period of time. In other words, even if a parachute design has been completed and the parachute manufactured, tests should be conducted to verify its performance and design characteristics.

A number of design criteria are available which permit the designer to determine at the outset, if not a completely new parachute design, then, what modifications of an established design can be made to effect his purpose, within the limits of attainable performance. The knowledge of these design criteria is largely due to the more exacting requirements for parachutes applicable to a variety of deceleration, stabilization, and recovery installations on high performance aircraft, supersonic missiles, and research rockets.

The purpose of this chapter is to present the most important design criteria for the design of parachutes, together with a variety of design details and details applicable to the fabrication of parachutes.

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CHAPTER V

SECTION I

PARACHUTE SELECTION CONSIDERATIONS

1.1 GENERAL.

Parachute canopy selection for any particular application will be a compromise in some respects. High drag and high stability will not be found in the same parachute canopy. High strength means increased weight and bulk. In general, the design of any parachute must be based on the particular application. Since there is a large range of applications and canopy types, there is a decided advantage to being able to narrow consideration for any one application to two or three canopy types. In most cases, the performance characteristics required will immediately exclude certain types of canopies from consideration.

1.2 CONSIDERATIONS FOR THE SELECTION OF A CANOPY TYPE.

1.2.1 CONSIDERATIONS. The following considerations must be given to any parachute selection. The considerations are not necessarily in the order of importance, since the order will change with the particular application. Also, it is not possible for any one parachute to be ideal for every consideration. Therefore, good parachute design requires the best possible compromise in the final product.

a. Characteristics of the parachute canopy itself, such as rate of descent; drag coefficient and change in drag coefficient with rate of descent; rapidity of canopy opening; squidding and critical opening speed; opening shock; stability, and stability change at various rates of descent; and maximum deployment speed.
b. Limitation of space, shape, and weight, as determined by the particular application.
c. Method of deployment.
d. Reliability requirement.
e. Initial cost.
f. Upkeep cost.
g. System variation possibilities, which are: ground shock absorption devices to permit an increase in rate of descent, or to afford required cushioning; reefing control for opening shock reduction or drag variation; canopy clustering or staging; requirements for special devices, such as automatic timers and disconnects; and the effect, if any, the configuration of the load has on the parachute canopy behavior during deployment or descent.

1.2.2 SELECTION OF CANOPY. Parachute designers can generally benefit by selecting a canopy type that has proven performance characteristics. New and theoretical approaches are desirable, but the cost, development time and facility requirements for testing are generally prohibitive.

As stated previously, a major consideration in selecting a particular canopy type will probably be the purpose for which it is intended. It is therefore convenient, in order to aid in the selection of a parachute canopy, to classify parachute uses and applications according to basic functions. In this tabulation, two or more of the basic functions appear in most applications; however, emphasis is placed here on the primary function which governs the selection and design.

1.2.2.1 Parachute Applications (Functions).

1.2.2.1.1 Steady or Controlled Descent.

a. Personnel.
b. Aerial Delivery.
c. Drone, missile or component recovery, or both.
d. Aircraft dive and landing approach control.
e. Mines, flares, and others.

1.2.2.1.2 Deceleration.

a. Aircraft in-flight and landing roll control.
b. Drone, missile and/or component recovery.

c. Aircraft emergency escape devices.
d. Auxiliary wheels.

1.2.2.1.3 Stabilization.

a. Missiles, bombs, torpedoes.
b. Aircraft emergency escape devices.

1.2.2.1.4 Extraction.

a. Aerial Delivery loads.
b. Aircraft component separation, fuel tanks.
c. Parachute pack (by pilot chute).

1.2.2.2 Secondary Functional Requirements. The type of application and, to a lesser extent, the parachute canopy type selected, together may determine the interralation between various other techniques, components, and auxiliary equipment, such as method of release or ejection, method of packing, type of deployment, construction of deployment bag (if required), type and size of pilot chute, and length and construction of riser and harness. These requirements, however, have little, if any, influence upon canopy design. The major considerations which will govern the choice of a method or construction of a component are absolute reliability and serviceability, with the widest practical margin of safety.

1.2.2.3 Operational Conditions for the Parachute. For each parachute application, performance requirements are generally given, which must be defined quantitatively in terms of maxima and minima. Generally, the knowledge of:

a. Gross load range.
b. Deployment speed range.
c. Altitude range.

is required to determine the strength characteristics of the parachute. The margin of safety of the parachute may be loosely defined, in relation to these conditions, as the percentage by which the maxima and minima may be extended beyond those specified without failure resulting.

In addition to the conditions stated above, the following operational characteristics must be known to determine canopy type and size:

a. Rate of descent.
b. Oscillation limits.
c. Allowable gravitational force limitations of load.
d. Allowable weight of parachute.
e. Allowable volume of parachute.

1.2.2.4 Applicable Canopy Types. Canopy type selection may now be made on the basis of the primary functional requirements and the desired operational conditions outlined above. Canopy types and their limitations are listed in Chapter II. Considerations such as previous operational experience, drag efficiency, reliability, and opening shock factor, may, however, further limit the choice. If the design conditions are not within the range of test experience and the available performance data for the canopy type selected, further canopy development will be required.

CHAPTER V

SECTION 2

PARACHUTE DESIGN CONSIDERATIONS

2.1 DRAG OF PARACHUTE CANOPIES.

The drag of a bluff shape, such as that of an inflated parachute canopy, is generally

$$D = c_D\, q\, S$$

wherein $c_D S$ = drag area

$$q = 0.5\, \rho\, v^2 \text{ dynamic pressure.}$$

Thus, the drag depends upon the size, represented by a suitable area S, the dynamic pressure q, and the canopy shape, which essentially determines the value of the coefficient c_D.

Two areas are generally representative for the size of a parachute canopy, the area of the canopy projected in axial direction, S_p, and the developed area of the material forming the canopy, S_o. The drag coefficient C_D, based on the projected canopy area, is used for Ribbed and Ribless Guide Surface canopies only, while the coefficient c_{D_o}, based on the total area, is used for all other types of canopies.

The value of the drag coefficient depends primarily upon the shape of the inflated parachute canopy and the porosity of the material used. The shape is a complex function of the canopy design, depending on parameters such as the type of construction, suspension line length, size and weight of the canopy, and the speed of operation. The porosity not only affects the drag directly, it also has an important influence upon the dynamic behavior (flow pattern) of the canopy. Oscillating or gliding, or both, parachute canopies have considerably higher drag coefficients than the more stable types.

Experimental values of the drag coefficients are listed in Chapter II. For preliminary calculations, the following values for drag coefficients may be used:

Type Parachute Canopy	Drag Coefficient
a. Flat Circular	$c_{D_o} = 0.75$
b. Extended Skirt	$c_{D_o} = 0.70$
c. Guide Surface (Stabilization)	$c_D = 0.95$
d. Guide Surface (Ribless)	$c_D = 0.80$
e. Guide Surface (Personnel)	$c_{D_o} = 0.72$
f. Rotafoil	$c_{D_o} = 0.78$
g. Shaped (Conical)	$c_{D_o} = 0.80$
h. FIST Ribbon	$c_{D_o} = 0.50$
i. Ring slot	$c_{D_o} = 0.55$

2.2 DRAG EFFICIENCY.

Drag efficiency of a parachute canopy may be defined by two expressions, depending upon whether weight or bulk is the critical design consideration.

$$\text{Weight — drag: } \eta_W = \frac{c_D S}{W_P}$$

$$\text{Bulk — drag: } \eta_V = \frac{c_D S}{V_P}$$

Wherein W_P = total weight of parachute canopy
V_P = total volume of parachute canopy.

In order to establish a basis of comparison for different canopy types, it is advisable to assume the same structural margin of safety relative to the opening shock under identical deployment conditions. It can then be seen

that a parachute canopy with a good drag coefficient and a high opening shock characteristic may have a poor drag efficiency because of the greater strength of materials required. This method may facilitate the selection of a canopy type by determining which of several different canopies designed for the same purpose provide the required drag performance for the least weight and bulk of material.

The fact that otherwise equivalent parachute canopies differ greatly in drag efficiency may be attributed largely to the differences in canopy geometry. This difference in canopy geometry, which changes the total cloth area without proportionally affecting the drag coefficient, may be made for the purpose of effecting improvements in canopy performance, such as: to increase stability, reduce opening shock, reduce local fabric stresses, or gain better controllability.

2.3 RATE OF DESCENT.

When using parachutes in vertical descents, the terminal vertical velocity follows from

$$V_e = \sqrt{\frac{2W}{\rho\,(c_D S)}} = \frac{32.7}{D_{ft}}\sqrt{W_t}$$

Wherein W_t = weight of suspended load and parachute.

It is to be noted that generally the velocity V_e is taken to be the vertical component of the parachute motion against the earth.

For convenience, Figure 5-2-1 has been plotted, indicating the canopy diameter D required as a function of the total weight W, for various rates of descent v_e, and for a drag coefficient $c_D = 1$. Note that D and C_D have to be defined to be consistent with each other, referring to one and the same area (S or S_o). For drag coefficient different from 1, the required diameter is proportional to $1/\sqrt{c_D}$, as indicated in the left hand side of the chart.

In case of parachute operation at altitudes higher than sea level, the reduced value of the air density ρ is very important. The ratios of ρ/ρ_o and $\sqrt{\rho_o/\rho}$ have been plotted in Figure 5-2-2. The terminal velocity of a parachute suspended load (as found, for example, in Figure 5-2-1) is proportional to the root term.

2.4 PARACHUTE CANOPY LOADING.

Parachute canopy loading may be defined as the ratio of maximum force (F_o) to the drag area of the canopy ($c_D S$). This ratio is generally applied for parachute canopy design consideration. The canopy loading under terminal velocity conditions may be defined as the ratio of total weight (F = W) to the drag area of the canopy ($c_D S$). Under terminal velocity conditions, a certain canopy loading will always give a certain rate of descent, independent of canopy size or weight involved. This relationship can be seen by considering this formula for rate of descent

$$V_e = \sqrt{\frac{2W}{\rho\,(c_D S)}} = \sqrt{\frac{W}{c_D S}}\sqrt{\frac{2}{\rho}} = \sqrt{\text{canopy loading}}\sqrt{\frac{2}{\rho}}$$

The above formula is graphically presented in Figure 5-2-3. Typical parachute canopy loadings versus rate of descent are plotted in this figure for all parachute applications. For aircraft approach and landing deceleration parachute applications, these figures are of theoretical value only; however, this graph gives an indication with respect to the calculation of parachute canopy opening forces in that parachute applications having a terminal velocity of over 100 ft./sec. may be considered as infinite mass cases. Personnel, aerial delivery, and final stage missile recovery parachute canopies have final rates of descent from 16 to 50 ft./sec. and a canopy loading $(\frac{W}{c_D S})$ from 0.3 to 3.0 lb./ft.^{2} Parachute canopies with canopy loadings between 3.0 and 25 lb./ft.^{2} are used in Ordnance applications for stabilization or deceleration purposes. For all other applications, parachute canopy loadings are higher. These applications may be treated as infinite mass cases.

While differences in canopy loadings under terminal velocity conditions $(\frac{W}{c_D S})$ must be considered in canopy design because they establish limits on canopy porosity, construction, and stability, design strength of parachute canopies is largely governed by the instantaneous canopy loading $(\frac{F_o}{c_D S})$. For FIST ribbon type parachute canopies, the required strength of ribbons for a given gore base width and instantaneous canopy loading is fairly well known. (See Figure 5-3-3.) For solid cloth parachute

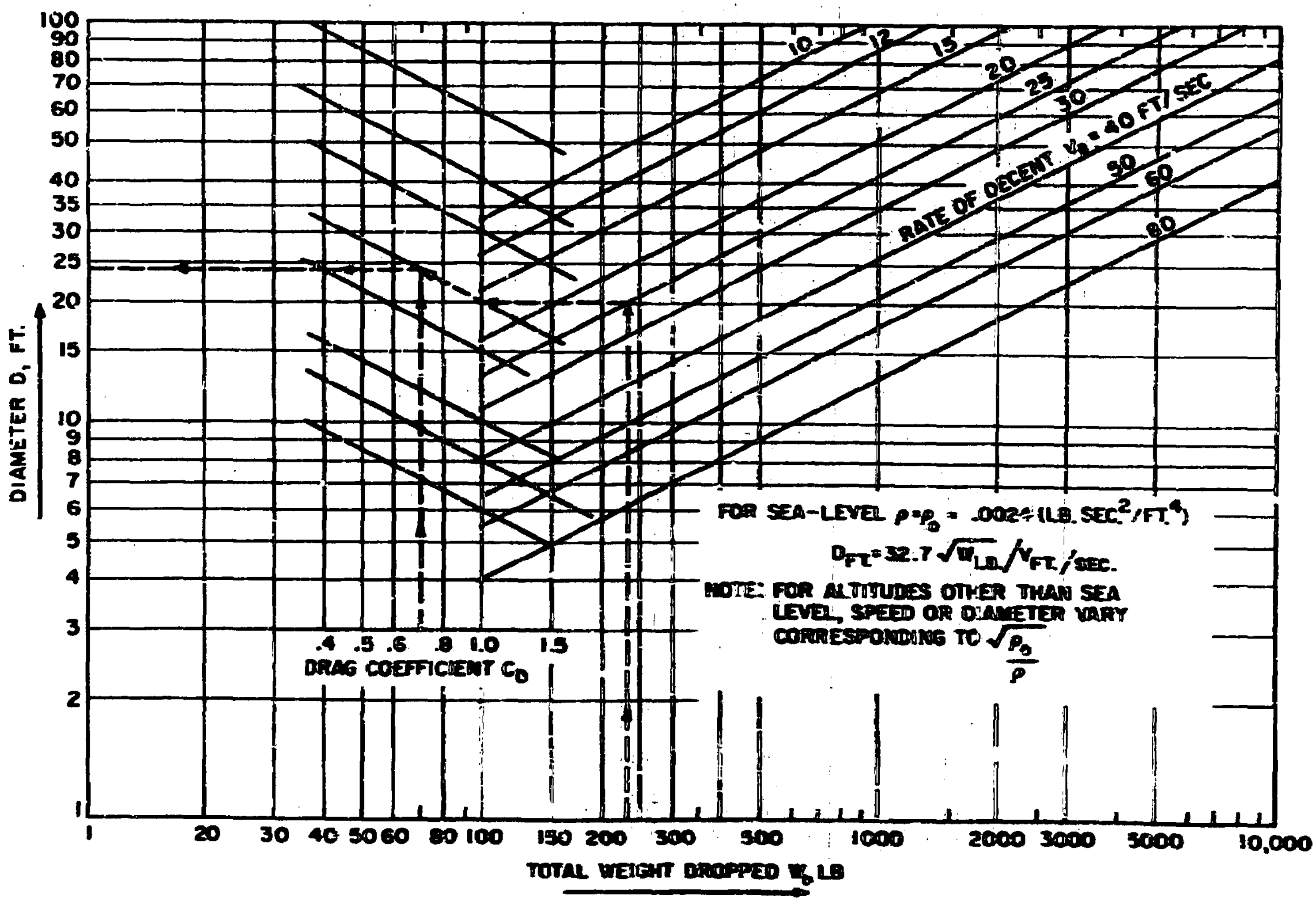


Figure 5-2-1. Parachute Canopy Diameter Required as a Function of Total Weight Dropped and the Rate of Descent

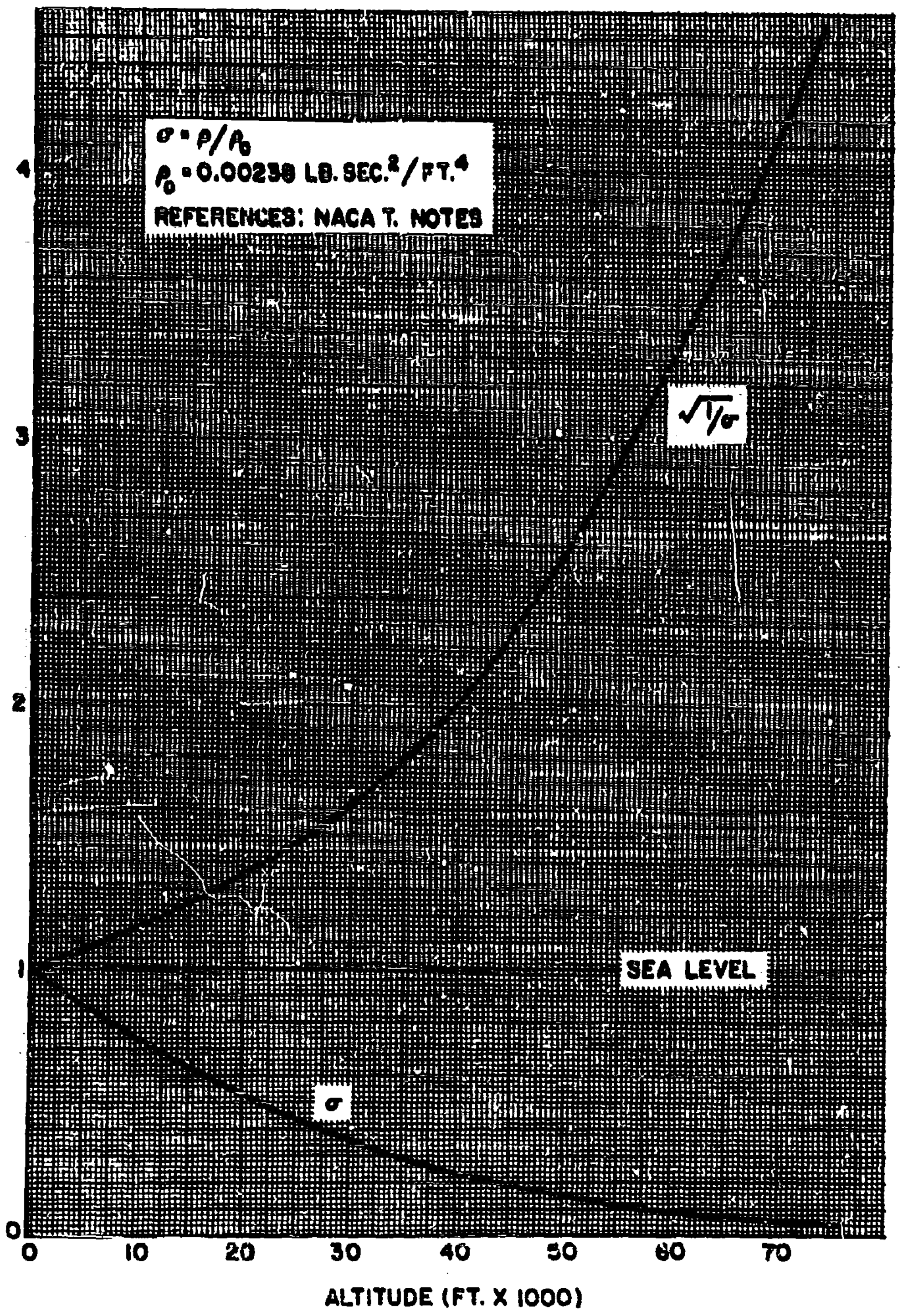


Figure 5-2-2. Variation of Air Density Ratio σ with Altitude

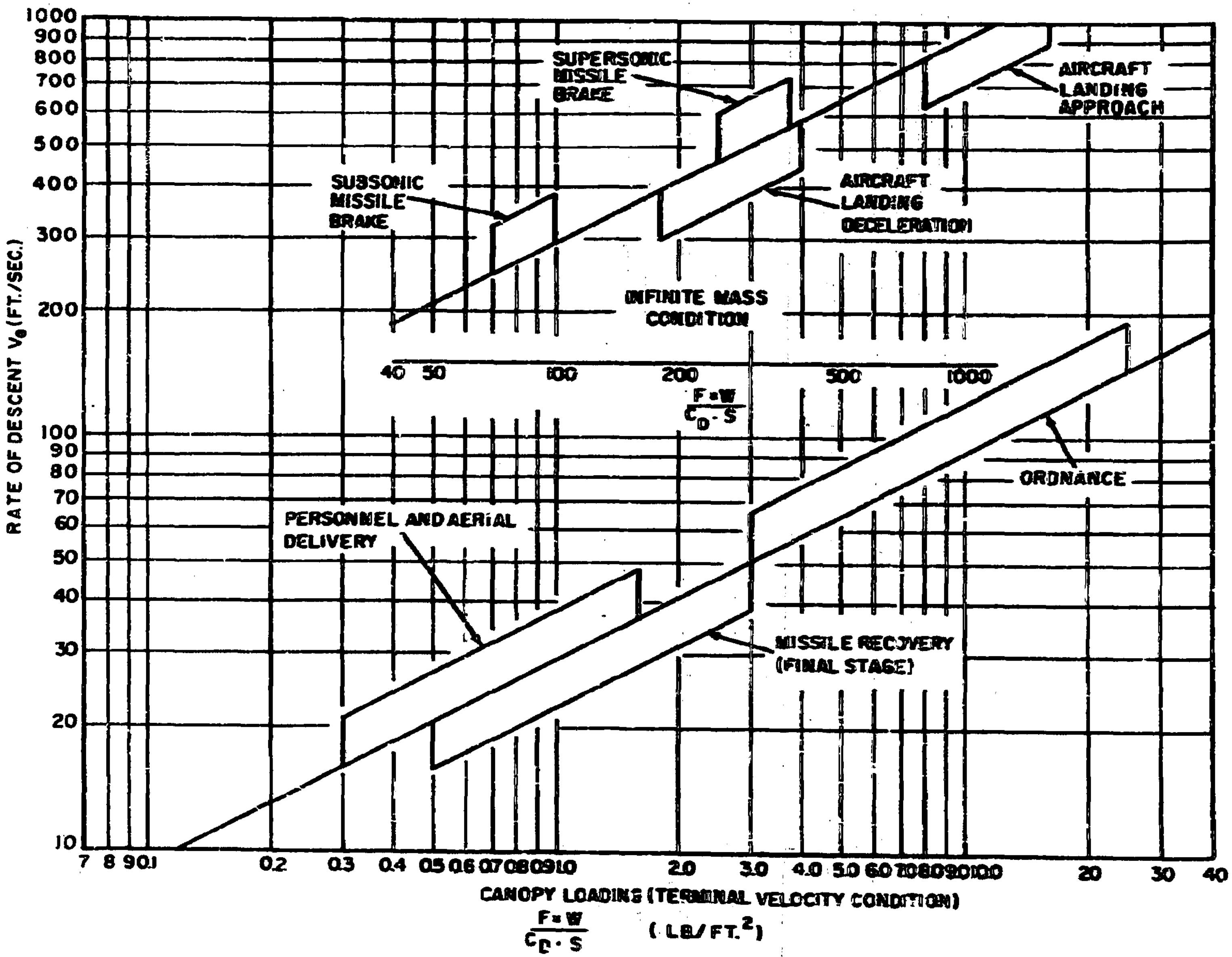


Figure 5-2-3. Rate of Descent Versus Parachute Canopy Loading For Terminal Velocity Conditions

canopies, these dependencies are being established.

2.5 SCALE EFFECT.

The absolute size of the parachute canopy is defined by the required drag area, when the drag coefficient is known. The required area may be divided among two or more canopies to form a cluster. This is generally advisable if the resultant canopy diameter is larger than is considered desirable or practical from the standpoint of serviceability. Parachute canopies in a cluster are usually of equal size.

When parachute canopies are used in clusters, a small loss of efficiency in the function of the canopies will be encountered. This decrease in efficiency is believed to result from the decrease in projected area of the individual canopies due to their canted attitude during descent, and also from a decrease in their gliding and oscillating tendencies.

If the scale for a particular parachute canopy is increased, the following changes in canopy performance will generally result:

a. The drag coefficient decreases
b. Filling time of the canopy increases
c. Canopy stability improves
d. The critical opening velocity decreases.

2.6 POROSITY.

The porosity of a parachute canopy arises from the openings in the canopy through which air can flow. These openings are generally of two types:

a. The air permeability of the canopy fabric
b. Openings deliberately constructed in the canopy.

Since the fabric is elastic, the pores and other openings through the fabric generally tend to increase in area with increasing air pressure. It is therefore important to know the porosity characteristics of parachute canopy material over the full range of dynamic pressures to which it may be subjected during application. This range extends from approximately 0.5 lb./ft.^{2} to 6000 lb./ft.^{2} and corresponds to velocities starting at 20 ft./sec. and approaching Mach 3. Fabric porosity is commonly expressed as the volume of air flowing through a unit area in a unit time at a specified constant pressure differential (ft.^{3}/min./ft.^{2}). Fabric porosity versus differential pressure for three types of parachute material is shown in Figure 5-2-4.

The major effect of porosity during parachute canopy operation is upon canopy opening. Success or failure of canopy openings is generally determined by the volume of air released through the canopy due to porosity and the limited inflow of air due to the choking effect of the canopy skirt. Therefore, in order to obtain positive canopy inflation in the case of solid fabric canopies, a balance has to be maintained between air flow into the canopy and air loss due to fabric porosity and the vent opening(s).

Geometric openings, in addition to the vent, are built into some types of canopies. These canopy types derive their performance characteristics from careful selection and spacing of openings. For these types of canopies, porosity is defined as geometric porosity

$$\lambda_g = 100 \frac{S_g}{S_o} \%$$

wherein S_g = total area of openings in canopy
S_o = area of canopy.

The effect of geometric porosity is felt, in proportion to its contribution to total porosity, only when it is distributed uniformly through many small openings, as in the ribbon type canopies.

2.7 STABILITY.

As stated before, good stability in a parachute canopy is obtained at the price of reduced drag

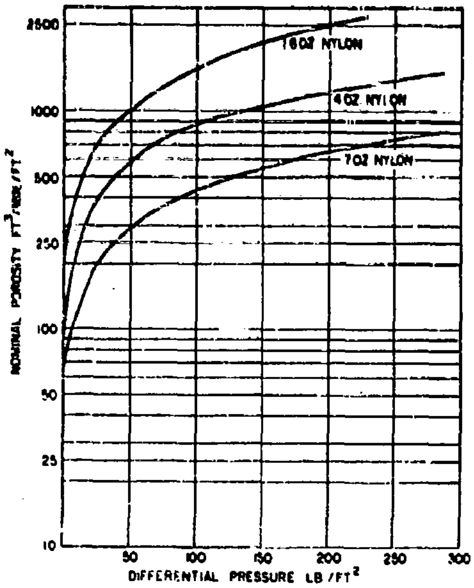


Figure 5-2-4. Fabric Porosity versus Differential Pressure

efficiency. Therefore, during the design phase, it is important to carefully assess the requirements of each particular application in terms of the ratio of stability gains versus efficiency losses. This may then lead to a revision of the possibly over-stringent stability range requirements.

A near approach to absolute dynamic stability is, in most cases, necessary only for such parachute applications as bomb stabilization. For certain applications, undamped oscillations or erratic gliding during descent may not be objectionable. For the great majority of first stage missile recovery applications, undamped oscillations of up to ±2° can be tolerated. For other parachute applications, a range of oscillation of up to ±5° is considered tolerable. While the objective for aerial delivery systems, final stage missile recovery, and personnel applications, is to reduce the incidence of damage and injury caused by swinging impact with the ground, stability ranges of between ±5° and ±20° are adequate, in a majority of cases, for these applications.

Generally, stability of parachute canopies deteriorates with decreasing velocity. This tendency may be caused by a reduction of restoring moment of the suspended load, together with an increased tendency of the canopy to glide.

2.8 CRITICAL OPENING VELOCITY AND OPENING SHOCK.

For reasons of safety, the critical opening velocity of parachute canopies having canopy loadings under terminal velocity condition of over 100 lb./ft.^{2} must be somewhat greater than the anticipated deployment velocity. Others may have critical opening velocities below maximum anticipated deployment velocity, but sufficiently higher than terminal velocity for inflation to be assured. Reliability requirements and minimum opening time may, however, dictate that critical opening velocity be approximately equal to or above anticipated deployment velocity.

With respect to critical opening velocity, the governing design parameters for a parachute canopy are:

a. Total porosity of canopy
b. Distribution of canopy porosity
c. Shape of the canopy mouth.

Generally, the shape of the canopy mouth during inflation is influenced by various geometrical factors, such as the shape of the gore pattern and the length of suspension lines. Since a certain amount of skirt slackness exists between suspension lines prior to canopy inflation, it is difficult to either control canopy mouth shape or predict the effect of such inflation promoting devices as pocket bands. Pocket bands are, however, effective in getting canopy inflation started by limiting the inward fold of the slack skirt material. If canopy inflation has started, it will continue to a state where either equilibrium is realized between the volume of air flowing into the canopy through its mouth and that flowing out through the fabric pores or other openings, or where equilibrium is reached between internal pressure and structural tension.

Several methods of improving opening characteristics of parachute canopies have been tried in the past, with varying degree of success. Among those methods are: adding pocket bands at the canopy skirt between adjacent skirt sections across suspension lines; lengthening suspension lines; substituting canopy crown material with low porosity fabric; or, adding external air pockets to the skirt. In the case of the guide surface type parachute canopies, and other shaped gore canopies, opening characteristics are to a certain extent, a function of gore shape. Primarily, however, opening characteristics are dependant upon porosity. Solid cloth canopy designs with inverted conical, or inward curving, skirts are more sensitive to porosity than the ribbon type designs. A small increase in porosity, due either to opening shock damage or to variations in textile weave, can reduce the critical opening velocity below a safe level. For this reason, very little geometric porosity can be utilized or tolerated in such canopies as the guide surface and extended skirt parachute canopy types. On the other hand, geometrically porous canopy designs, such as those of the ribbon family, in which the total porosity required for stability is close to the critical limit, are sensitive to variations in fabric porosity.

When considering parachute canopy opening shock, canopy filling time is a major factor. The filling time of a parachute canopy may be increased by increasing the total porosity of the canopy, or by shaping the gores to curve inward to retard the opening rate of the canopy mouth. Another method used to increase canopy filling time is skirt reefing.

2.9 CANOPY GEOMETRY.

When considering the effect of canopy geometry upon canopy performance, attention should be paid to the fact that canopies of large diameter are neither geometrically nor mechanically similar to canopies of small diameter, even though they may be of the same basic design. This may be explained by means of two factors associated with the scale effect, namely, the number of gores varies, and the weight and flexibility of the materials vary. This consideration serves to point out again that, even if the geometry of a parachute canopy has been found suitable by constructing and testing smaller scale models, full size parachute canopies should also be drop tested.

The inflated profile of a typical circular parachute canopy is shown in Figure 5-2-5. This profile is that of the radial seam, or rib, and no attempt has been made to indicate the profile of the panel bulges between ribs. Because of the panel bulges, the profile shown represents the limiting shape with an infinite number of gores. However, a canopy designed as a surface of revolution usually does not, because of the gore shape, pull in appreciably at the skirt and so shows the least variation in profile with number of gores.

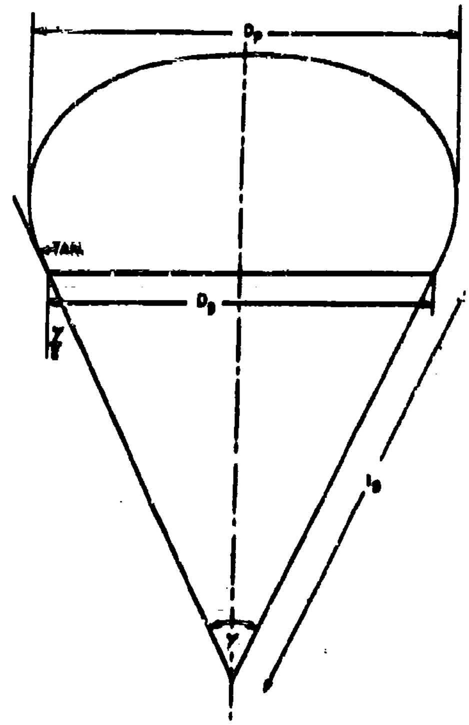


Figure 5-2-5. Inflated Profile of a Typical Circular Parachute Canopy

The skirt lip will be tangent to the suspension lines, if it is assumed that no bending stresses are present. Under this assumption, the canopy skirt assumes a negative angle of incidence. This negative angle is at this point, half the angle enclosed by the suspension lines. The negative angle of incidence of the skirt and, more important, the length of the conical surface to the tangency point, have a strong influence upon several important characteristics. As the length of the conical surface is increased, the critical opening velocity is reduced, canopy filling time is increased, opening shock is reduced, the average angle of oscillation is decreased, the damping characteristics are improved, and the ratio of D_p to D_s is increased. These effects appear in varying degrees in the performance of the extended skirt and guide surface type canopies. In general, the smaller the relative canopy mouth becomes, the lower the allowable porosity of the canopy becomes, if the critical opening velocity is to be maintained at a safe value. Because of the scale effect, this trend becomes more pronounced as the diameter is increased, but beyond a certain point the area of conical surface extensions required for stability and other desirable performance characteristics diminishes, approaching zero for very large parachute canopies. Experience indicates that this limit is reached when the diameter approaches 80 ft.

Other geometric shape factors associated with the skirt of circular canopies can be observed to a marked degree in the performance of ribbed and ribless guide surface type parachute canopies. Here, the pronounced bulges or lobes, as well as the high rate at which the crown profile breaks away from the tangency point on the conical surface (thus producing a flattened top), determine to a large degree the performance characteristics of this type of canopy. In these canopies, the separation line between crown and conical surface can be considered a flow separation edge, which creates the same effect as that obtained through the use of high porosity fabric.

2.10 STRENGTH.

The precise determination of parachute strength is, at present, partially handicapped by a lack of accurate quantitive data; therefore, parachute design relative to strength can only be approximated. Strength criteria unavoidably entail two

closely related considerations, namely, weight and bulk. These considerations relate primarily to the selection of existing parachute canopy types of the weight class required. What is more important, however, is to insure that all detail requirements are so integrated that a parachute structure of maximum efficiency can be produced.

The overall strength requirements for a parachute canopy and other components are readily established by applying a design factor to the allowable maximum opening shock. This design factor is commonly specified in relation to the particular application, either to limit the maximum deceleration imposed upon the suspended load, or to limit the structural weight required in all components of the system. At present, dependency is placed upon tensile tests to destruction of structural samples, combined with drop tests of the complete assembly, to demonstrate that a margin of safety exists for the given design conditions. Insofar as the suspended load alone is affected, an additional margin of safety is provided by the ability of the parachute to sustain extensive damage and still function properly.

CHAPTER V

SECTION 3

PARACHUTE DESIGN DETAILS

3.1 GENERAL.

The physical differences between the various parachute types are primarily those of construction and detail geometry. For all parachutes, materials and fabrication methods are more or less uniform. A few parachute types also employ special members, devices, or auxiliary mechanisms, which affect the performance characteristics, method of control, and installation requirements.

3.2 PARACHUTE CANOPY.

A parachute canopy, by definition, consists of the drag producing surface (cloth area) and the suspension lines. The more common types of drag producing surface are divided into identical gores, which are, in turn, dived into sections. The shape of the gores determines both the constructed and the inflated shape of the drag producing surface. The gores may be constructed of solid fabric, or of some geometric pattern of fabric strips or ribbon. The gores are joined by a radial seam running from the vent to the skirt. Because the suspension lines are, in a majority of cases, attached to the skirt at the radial seams, additional strength along these seams is required. This strength is generally obtained by seam reinforcement with webbing or tape, or by extending the suspension lines along the radial seams. In some cases, it is necessary to add reinforcements to critically stressed portions of the drag producing surface. The most common form of reinforcement which is found on nearly all canopy types, consists of bands along the skirt and the vent. Additional circumferential reinforcement bands are sometimes needed at intermediate locations on the drag producing surface.

3.2.1 DRAG PRODUCING SURFACE. The constructed shape of the drag producing surface varies widely between types. This difference is mainly effected in the layout of the gore pattern. Noncircular drag producing surfaces, however, also differ as a result of their symmetrical gore construction. For rotationally symmetrical surfaces, the width of the gore in relation to its radial dimensions determines whether the assembled envelope will tend to restrict the diameter or allow the surface to assume a free inflated shape.

In regular polygon surfaces, the included angle of the gore in conjunction with the number of gores determines whether the drag producing surface will be flat, conical, or merely have additional transverse fullness in the gores when inflated. The tendency of an inflated elastic envelope to assume a curvature of uniform surface tension ensures that the maximum included gore angle (projected) will always be equal to 360/n degrees. Of course, variations from this basic pattern of radial elements can cause the drag producing surface to assume any shape desired. The flat circular type of drag producing surface which is made in the form of a regular polygon built up from n triangular gores, is a special case in that no preshaped structural limitations are placed on the free development of the surface. Assuming that the suspension line length is great enough to have only a negligible effect on the inflated profile, the skirt will tend to pull inward to an equilibrium position where each gore belly has a semi-circular cross section. This canopy profile is shown in Figure 5-3-1. If the number of gores in a flat circular drag producing surface is large, the ratio of the projected diameter (measured between opposite panel bellies) to the flat diameter (measured between opposite corners) is approximately 0.7. The ratio D_p/D_s = 0.7 represents a good average value for preliminary design purposes.

The free inflated shape of the drag producing surface is not readily predicted from the shape of the gore, except for those pattern types that define surfaces known to fall entirely within the envelope of aeroelastic equilibrium. Therefore, in designing a new parachute canopy for a desired inflated shape, it is usually necessary to estimate the gore pattern on the basis of experience and then modify it after building and testing the first experimental model. The other approach, which is the more common one, is to base the gore pattern on some easily

defined or aerodynamically desirable geometric shape, such as the sphere or cone, and evaluate the performance of whatever inflated shape might result from it. This method, however, also may not produce a desired shape or certain performance characteristics during the first attempt, and may require additional modifications.

3.2.1.1 Strength Requirements. At the present time, no widely applicable system exists for a determination of the strength required to prevent failures in the drag producing surface.

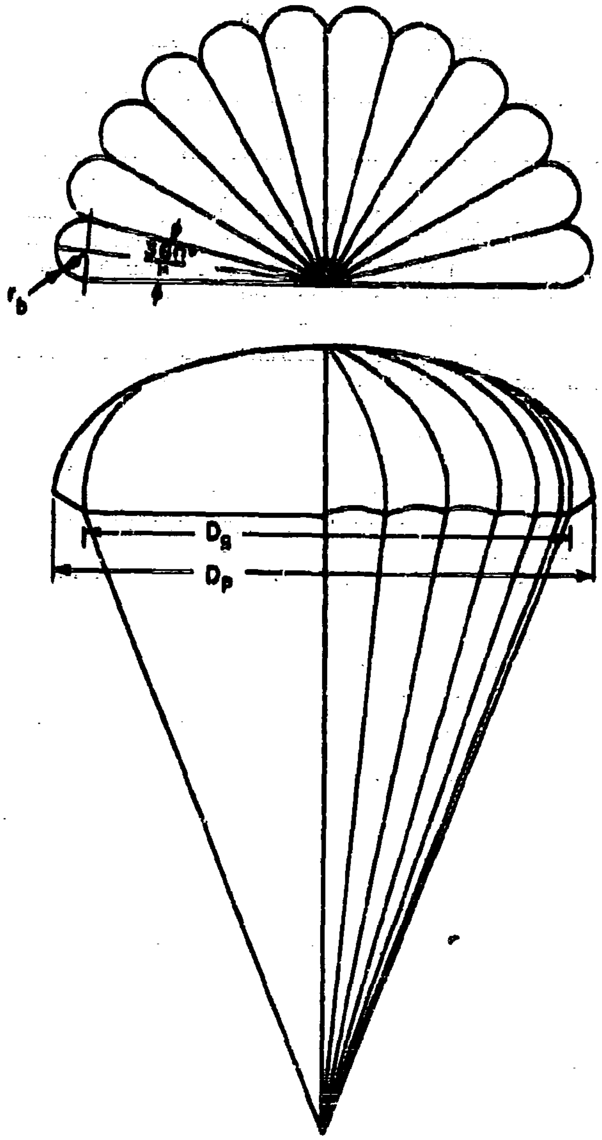


Figure 5-3-1. Inflated Profile of a Flat Circular Type Parachute Canopy

One method for determining the approximate forces acting in the plane of the fabric in the drag producing surface is being used. This method assumes that the pressure differential between the internal and external fabric surface at zero degree pitch angle is approximately the same over the entire surface, and that radial forces are so small that they may be neglected. If one assumes a small strip of fabric taken from the drag producing surface and curved only in a plane illustrated in Figure 5-3-2, then

$$P = p \cdot r_b \cdot d\alpha$$

and

$$T_h = \frac{P/2}{\sin d\frac{\alpha}{2}}$$

Since $d\alpha$ is a very small angle, $\sin \frac{d\alpha}{2}$ can be substituted by $\frac{d\alpha}{2}$. The force traveling in the fabric up to the main seams can then be expressed as

$$T_h = \frac{1/2\, p \cdot r_b \cdot d\alpha}{d\frac{\alpha}{2}}$$

or

$$T_h = p \cdot r_b$$

The force T_h is constant in the range between two main seams, since the pressure on this strip of fabric acts only vertically to its surface and the strip remains flexible. If it is presumed that the pressure p is constant over the entire drag producing surface, then the radius r_b is also constant and the fabric between two main seams forms a circular arc. The value for the radius r_b depends largely on the pattern of the drag producing surface. Representative values of r_b for several types of drag producing surfaces, including the flat circular type, are in the order of 0.5 to 0.6D. For Ribbed and Ribless Guide Surface types, maximum values for r_b have been determined to be approximately 0.2D.

A second method for the determination of the approximate strength requirements for a drag producing surface is based on the strength of the suspension lines correlated with the strength of the drag producing surface, assuming that a fairly constant proportion of suspension line and fabric strength exists if a certain choice of suspension line and surface material is made. For FIST Ribbon type parachute canopies, a balanced relationship between suspension line and surface material may be assumed to be as follows:

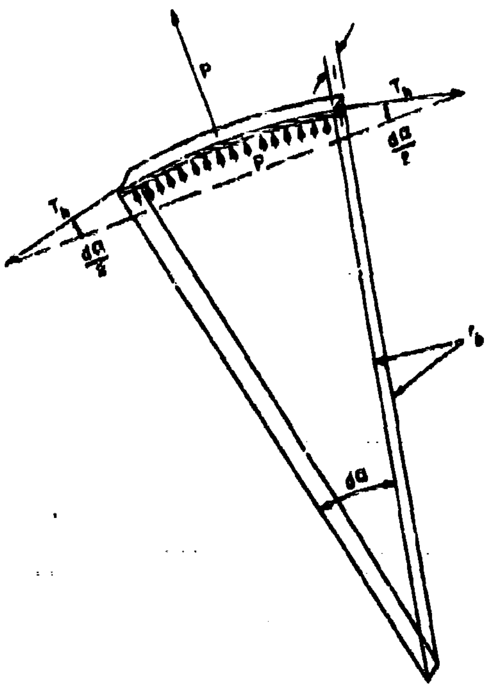


Figure 5-3-2. Forces Acting on a Small Strip of a Drag Producing Surface

Class	Suspension Line Material	Ribbon Material
I	375 lb. T.S. Nylon	100 lb. Ribbon, Nylon
II	550 lb. T.S. Nylon	200 lb. Ribbon, Nylon
III	1500 lb. T.S. Nylon	300 lb. Ribbon, Nylon
IV	3000 lb. T.S. Nylon	500 lb. Ribbon, Nylon
V	6000 lb. T.S. Nylon	1000 lb. Ribbon, Nylon
VI	12000 lb. T.S. Nylon	1700 lb. Ribbon, Nylon

For all other types of parachute canopies, this relationship may be assumed to be as follows:

Class	Suspension line Material	Surface Material
I	375 lb. T.S. Nylon	1.1 oz. Nylon
II	550 lb. T.S. Nylon	1.6 oz. Nylon
III	1000 lb. T.S. Nylon	2.25 oz. Nylon
IV	3000 lb. T.S. Nylon	4.75 oz. Nylon
V	6000 lb. T.S. Nylon	7.0 oz. Nylon
VI	12000 lb. T.S. Nylon	14.0 oz. Nylon

Assuming that parachute canopies are constructed in accordance with the classes outlined above, and that a fairly constant proportion of suspension line and fabric strength is thus assured, the following assumptions can be made:

a. Losses of strength in suspension lines due to sewing and attachment of fittings and reinforcements generally amount to about 35 percent of the original strength of the material.

b. Parachute deployment and inflation sequences cannot, at present, be considered so perfect as to allow assumption of ideal and equal distribution of load throughout the parachute canopy during the opening process; i.e., some portions of the canopy receive loads disproportionately high in comparison with the loads imposed on other portions.

Test data show that flat circular, Extended Skirt, FIST Ribbon, Ring slot, and Guide Surface type canopies begin to fail at roughly 40 percent of the theoretical suspension line strength, or, considering losses due to sewing, approximately 60 percent of actual suspension line strength. Satisfactory operation may continue above 40 percent, or failure may occur below 40 percent. This figure is approximate only. It is recommended, however, that if calculation of opening shock shows a total force of approximately 40 percent of the assumed total theoretical suspension line strength of a certain canopy design of a given class, the next stronger class of the particular design be utilized.

For FIST Ribbon type canopies, a more accurate method has been obtained from test data for determining the required strength of the horizontal ribbons for a certain ratio of opening shock (F_o) to drag area ($c_{D_o} S_o$) to skirt gore width. This relationship is shown in Figure 5-3-3. If the required strength is above the curve limit, the next higher ribbon strength or, in some cases, reinforcement, should be used with the horizontal ribbons.

Flat circular type drag producing surfaces show increasing fabric tension along the gore surface, moving inward from skirt to vent. Although various construction techniques are employed to provide fabric fullness in the vent area, it is well established that opening shock damage usually appears first in the area around the vent.

Little can be done with canopy geometry to relieve stresses imposed by whipping action and opening shocks occurring at high velocities, but the gore pattern can be proportioned to give minimum fabric tension under conditions of uniform pressure loading. A good example of this type of design is illustrated in the geometrical proportions and gore pattern of a typical Guide Surface parachute canopy.

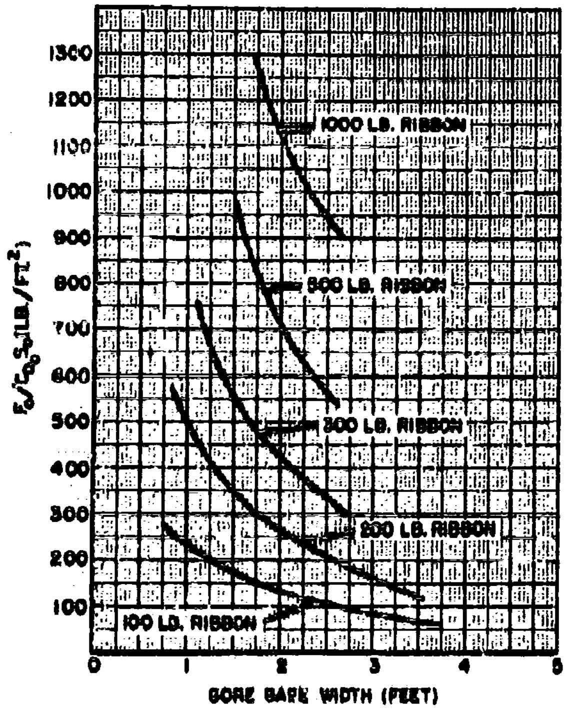


Figure 5-3-3. Boundary Curves for Horizontal Ribbon Strength of a FIST Ribbon Type Canopy

5.2.2 GORE DESIGN. In the past, gores designed by attempting to derive gore coordinates analytically have not been too successful as far as the performance of the resulting parachute canopy is concerned. This may be attributed mainly to the large number of variables involved in the actual physical process of parachute canopy functioning. Experience has shown that descriptive geometry remains the most direct and satisfactory method of gore designing, when it is supported by test observation. If the shape of a drag producing surface is to be designed, rather than some approximate geometrical construction, a number of considerations are applicable. It may first be assumed that the primary design objective is to obtain maximum drag efficiency in combination with a defined degree of stability. The attainment of a good drag efficiency implies a low opening shock characteristic and adequate distribution of fabric stresses so that minimum weight materials may be used. The attainment of a good degree of stability may require an inverted conical skirt, both conical skirt and flattened roof, geometric porosity, or both conical skirt and limited geometric porosity. On the other hand, the attainment of a good drag efficiency also requires that the projected area, relative to total cloth area (S_p/S_o), be a maximum, and that the total porosity be a minimum.

One promising line of approach appears to be the solid shaped-gore type of drag producing surface. Once the desired inflated profile has been defined, several specific considerations become pertinent to the determination of the gore coordinates. The drag producing surface may first be treated as a surface of revolution generated by the desired profile. This is illustrated in Figure 5-3-4. When a suitable number of gores has been assigned, the gore width at any radius is defined as the length of the arc

$$a = \frac{2\pi r}{n}$$

and the ordinate at distance s is

$$y = \frac{a}{2} = \frac{\pi r}{n}$$

If additional fullness is desired between the main seams, a bulge radius r_b may be defined to establish the slightly greater gore width, d,

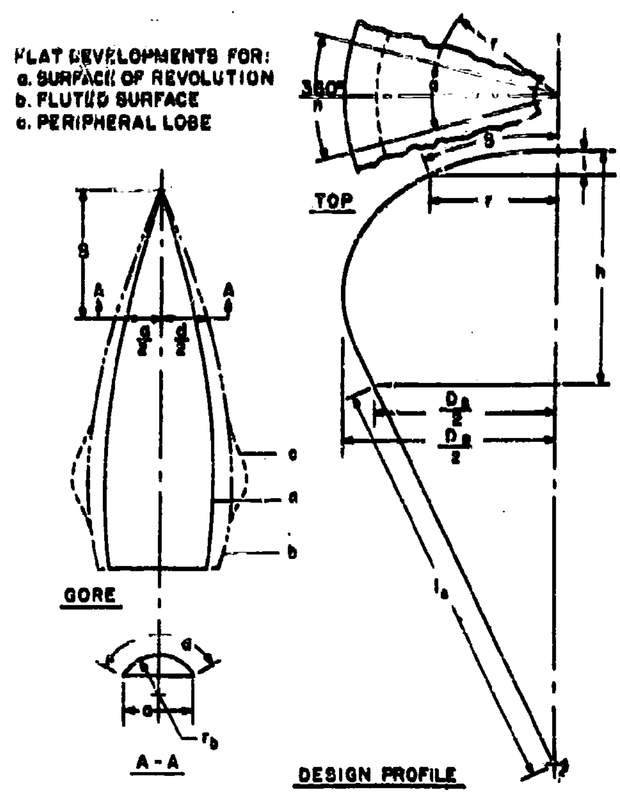


Figure 5-3-4. Shaped Gore Parachute Canopy Layout

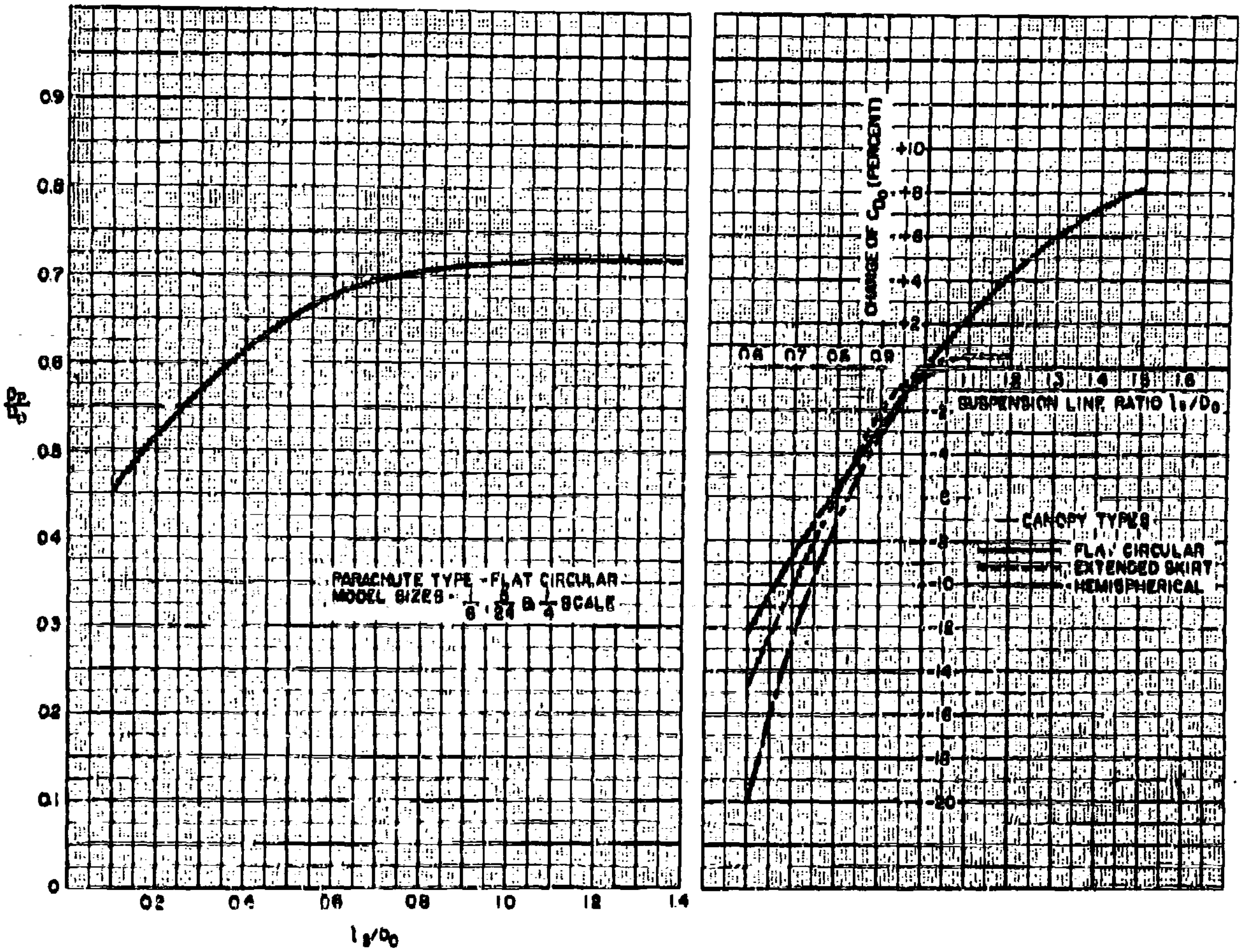


Figure 5-3-5. Effect of Suspension Line Length on Projected Diameter for a Flat Circular Type Model Parachute Canopy and on the Drag Coefficient for Various Types of Canopies

of the lobed surface. This bulge radius has to be established with due allowance for the elasticity of the fabric and the further effect of shortened suspension lines over the drag producing surface. A lobe may be produced at the periphery by a local widening of the gore in the region of a max; however, the effect on the inflated shape cannot be predicted with a certainty and model tests will have to be conducted so that suitable adjustments of the gore pattern may be determined by measurement.

Flat circular, conical, and many shaped gore type canopies pull inward at the skirt when inflated, forming the characteristic scalloped or lobed appearance in the peripheral region. This behavior, in conjunction with fabric elasticity, may be utilized to advantage in approximating a desired inflated canopy shape having minimum fabric tension with a relatively simple gore pattern. The essential consideration involved is the advantage of having greater fullness in the critical pressure region near the vent area than in the less heavily loaded skirt area.

3.2.3 SUSPENSION LINES. Depending upon the purpose and choice of the designer, the length of suspension lines to be used with different types of drag producing surfaces may vary. For nearly all known types, suspension line lengths range between 0.5 and 2.0D; however, the great majority fall between 0.7 and 1.3D. Tests have shown that the influence of suspension line length on the inflated shape of the drag producing surface and its performance generally becomes negligible above a ratio of $l_s/D = 1.0$. For comparative evaluation purposes, this value is commonly used; however, shorter suspension line lengths have been, and may be, used in service. The effect of suspension line length on projected diameter for a flat circular type model parachute canopy and on the drag coefficient for various types of canopies is illustrated in Figure 5-3-5. Since some

variation of effect occurs from type to type, it is good practice to determine and specify the optimum length of suspension line to be used with each type of drag producing surface in relation to the specific function which it is to perform.

3.2.3.1 Strength Requirements. The suspension line system can be considered as a group of tension members which extend from the skirt of the drag producing surface to the riser connection point. Prior to line stretch, the lines are extended by the drag of the drag producing surface and assume many shapes other than straight. As the drag load is increased to a maximum, the lines are so straightened that the only load considered is the one transmitted from the drag producing surface to the riser. Assuming that the load is uniformly distributed among Z number of lines, the load per line is determined by the geometrical configuration of the structure and is

$$\frac{\text{load}}{\text{line}} = \frac{\text{Drag}}{Z \cos\frac{\gamma}{2}}$$

This is true at any time during the descent period as long as the lines are assumed to be straight. In service, the maximum line load may occur at a drag value less than minimum, since it is possible that the maximum drag F_o, and maximum confluence angle γ, do not occur at the same time. However, the severest condition would be a line load based on a maximum drag and maximum confluence angle. The maximum possible angle is that based on an unextended suspension line and the mouth diameter in the fully distended position. This distension beyond a steady-state position is common in many types of parachute canopies, such as the flat circular type, while in others, such as the Guide Surface type, it is not as severe. This distension is commonly disregarded and the confluence angle is based on the unstretched line length and the skirt diameter D_s, or the inflated projected diameter D_p, in the steady-state condition. Because of the extreme variation in opening characteristics, the ideal case, in which it is assumed that the total load is uniformly distributed among the lines, is seldom achieved. For all practical purposes, however, the load to be expected in the lines can be predicted, and a suitable textile material can be selected. The method of attaching the suspension line to the drag producing surface greatly affects the amount of strength available. The two major attachment points are the juncture of the suspension line to the skirt of the drag producing surface and the juncture of the suspension line and riser. These attachment points are discussed in detail in Section 4 of this Chapter.

3.2.4 CANOPY DESIGN FACTORS. Design factors for parachute canopies may vary for different applications. Since every effort should be made to design a balanced canopy, identical design factors apply to both the suspension lines and the drag producing surface. The suspension line is selected on the basis of its static breaking strength. Although the actual breaking strength is often larger than the minimum value in the specification, the strength is commonly based on the latter value. The breaking strength of each suspension line may be expressed by the equation

$$\text{Strength} = \frac{F_o \cdot j \cdot c}{Z \cdot u \cdot o \cdot e \cdot k}$$

where F_o = maximum opening force
j = safety factor
Z = number of suspension lines
c = factor related to suspension line convergence angle
u = factor involving the strength loss at the connection of suspension line and drag producing surface or riser respectively
o = factor related to strength loss in material from water and water vapor absorption
e = factor related to strength loss by abrasion
k = factor related to strength loss by fatigue.

The value of these factors varies for different canopy applications. Design factor values are tabulated in Table I. The factor c, which is related to suspension line convergence angle, will change with suspension line length. For $l_s = D$, the factor c is approximately 1.055.

3.2.5 FLAT CIRCULAR TYPE CANOPY. The circular canopy may be generally described as a regular polygon of five or more sides. The drag producing surface is made up of a number of triangular gores, which are stitched together. The joints form the radial, or main, seams. The central vent, which is provided primarily for convenience of construction, has an area of less than 1% of the total cloth area (S_o). The skirt and vent hems are reinforced by rolling a tape or webbing inside the hem. Each gore may be made of a single piece of cloth (block cut) or of several sections cut on the bias and joined selvage to selvage, forming a star pattern of diagonal seams in the finished assembly. Bias construction is preferred because of its higher structural strength.

TABLE I

Application	Safety Factor	Decreasing Factors						Design Factor
	j	s u	Nylon	Silk	Rayon	e	k	j u · o · e · k (Nylon)
Paratroop Use	2.0	0.8	0.95	0.8	N/A	0.95	0.95	2.915
Personnel Emergency Escape	2.0	0.8	0.95	0.8	N/A	0.95	0.95	2.915
Aerial Delivery of Cargo	1.5	0.8	0.95	0.8	0.5*	1.00	0.95	2.080
A/C Landing Deceleration & Approach	1.5	0.8	0.95	0.8	N/A	0.95	0.95	2.185
Missile & Capsule Recovery, Deceleration Stages	1.9	0.8	0.95	0.8	N/A	0.95	0.95	2.770
Missile & Capsule Recovery, Final Stage	1.2	0.8	0.95	0.8	N/A	0.95	0.95	1.750

Figure 5-3-6 shows the planform, shape, and gore of a typical flat circular parachute canopy. The suspension lines are generally attached to the skirt at the main seams and so are equal in number to the number of gores. After passing through the channel formed by the main seam, the suspension lines are again fastened at the vent, pass across the vent of the drag producing surface, and follow inside the channel formed by the opposite seam. Two suspension lines are thus formed by a continuous line. Generally, the radial length of the line is made approximately 5% less than the radius of the drag producing surface, providing fabric fullness to relieve radial stresses in the gores. When the number of gores is less than approximately twenty-four (24), the total cloth or design surface area may be more accurately determined from the formula

$$S_o = \frac{\pi_o}{4} D^2$$

Wherein π_o = polygon shape factor for number of sides.

Values for the polygon shape factor as related to the number of gores in a flat circular drag producing surface are tabulated below.

Number of Gores	π_o
5	2.378
6	2.598
8	2.828
10	2.939
12	3.000
16	3.062
20	3.090
24	3.106
∞	3.140

3.2.6 EXTENDED SKIRT TYPE CANOPY. Originally, the extended skirt type parachute canopy was made by modifying a flat circular type canopy with a restricted extended section attached to the skirt hem in such a manner as to slightly decrease the normal convergence angle of the suspension lines at the extension hem. In present designs, the gore is created by the construction of a "formed gore," which includes this extension. Extended skirt lengths in the range of from 10% to 15% of the major flat diameter of the drag producing surface have been tested; however, the trend of development is toward the 14.3%, or "full", extended skirt. The planform, shape, and gore of a typical extended skirt type parachute canopy is shown in Figure 5-3-7. In other respects, the design of this canopy type parallels that of the flat circular type canopy. For most efficient canopy operation and performance, a suspension line length of $l_s = 0.95\ D_o$ is recommended.

3.2.7 PERSONNEL GUIDE SURFACE TYPE CANOPY. The personnel guide surface type canopy was developed to obtain a canopy having a drag efficiency equivalent to that of the flat circular type canopy, with improved stability

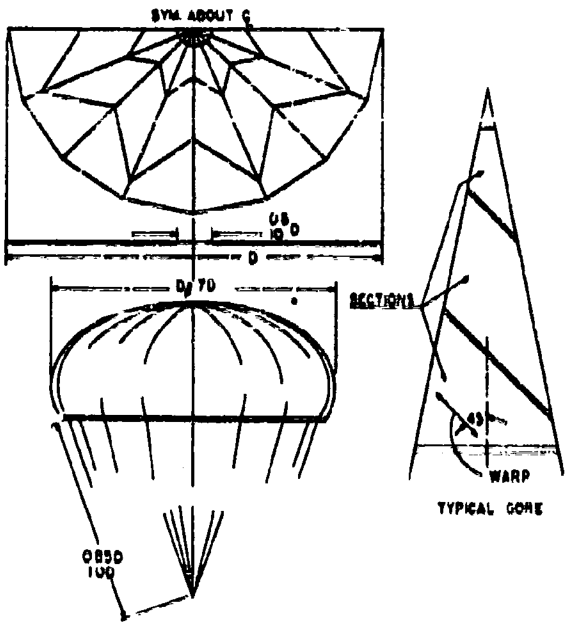


Figure 5-3-6. Flat Circular Type Parachute Canopy

and lower opening shock characteristics. This design goal was achieved by improving aerodynamic stability through shaping of the extensions to form guide surfaces. At present, the percentage of skirt extension cannot be calculated and must be experimentally determined for each particular application. Normally, every second gore is equipped with an extension. The present personnel guide surface canopy, Type C-10, is based on a flat circular drag producing surface that is 23 ft. diameter and contains 24 gores. The solid portion of the drag producing surface is slightly conical by virtue of the fact that 4 of the original 28 gores have been removed. Twenty percent interference extensions, shaped to form guide surfaces, are added to each alternate gore. The inflated shape and gore layout of this canopy type is shown in Figure 5-3-8. In other respects, the design of this canopy type parallels that of the flat circular canopy.

3.2.8 RIBBED GUIDE SURFACE TYPE CANOPY. This canopy is made of solid cloth with a relatively flat roof section and an inwardly sloped conical shaped surface extending downward from the roof along the suspension lines. In order that the drag producing surface might form the guide surface and flow separation edge required for stabilization, ribs are placed between the roof and guide surface sections and the suspension lines. The roof and guide surface panels are made of low porosity cloth cut on the bias at an angle of 45° to the central axis of the gore. Little or no vent opening is provided. The planform and shape of the typical ribbed guide surface canopy is shown in Figure 5-3-9.

Layouts for the roof panel, guide surface panel, and rib for a stabilization type ribbed guide surface parachute canopy are illustrated in Figure 5-3-10.

3.2.9 RIBLESS GUIDE SURFACE TYPE CANOPY. The ribless guide surface canopy is a refinement of the ribbed guide surface canopy and is designed, as the name implies, without ribs. The planform, shape, and gore of a typical ribless guide surface type canopy is shown in Figure 5-3-11. Dimensions for roof and guide surface panels depend upon both diameter and gore number of the drag producing surface. Dimensional factors for 12 and 16 gore ribless guide surface parachute canopies are shown in Figure 5-3-12. In other respects, the design

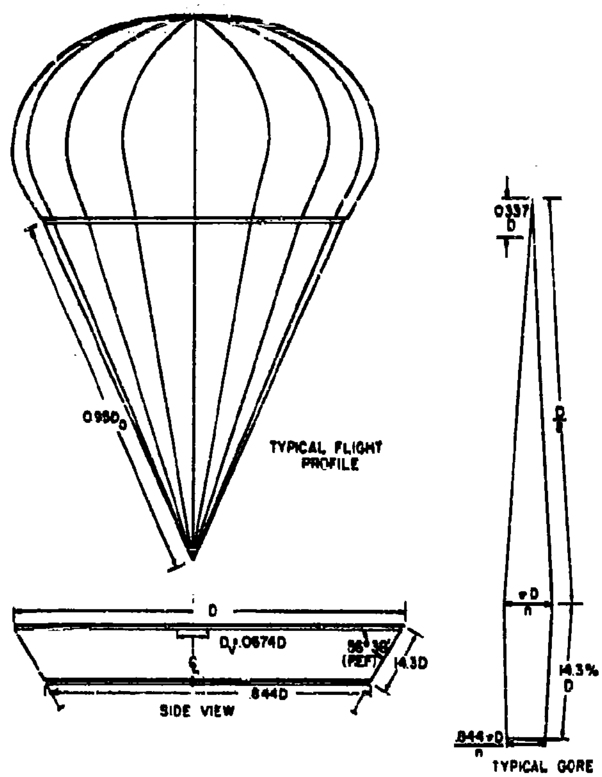


Figure 5-3-7. Extended Skirt Type Parachute Canopy

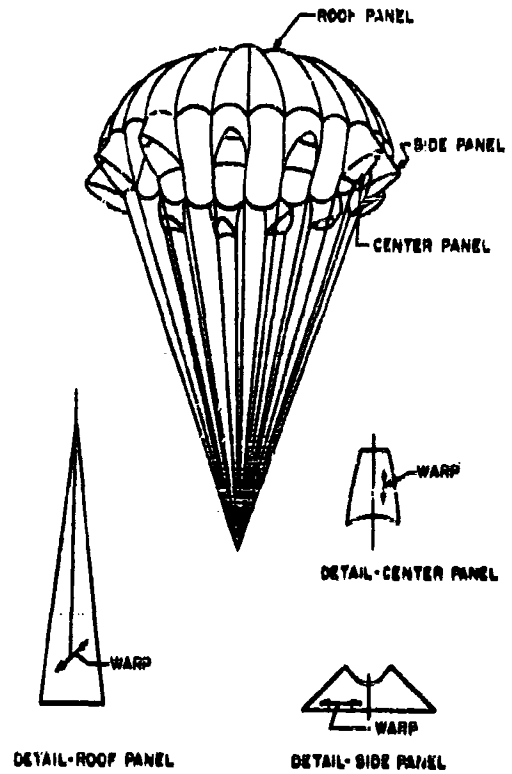


Figure 5-3-8. Personnel Guide Surface Type Parachute Canopy

of this canopy type parallels that of the ribbed guide surface canopy.

3.2.10 FIST RIBBON TYPE CANOPY. The FIST ribbon canopy is composed of concentric ribbons supported by a number of radial ribbons, which transmit the loads to the suspension lines. The planform and shape of a typical FIST ribbon type canopy are illustrated in Figure 5-3-13. As in the conventional flat parachute canopy, the gores of a FIST ribbon type canopy are constructed as flat triangles. The gore construction is illustrated in Figure 5-3-14. The gores consist of wide ribbons running parallel to the skirt (horizontal ribbons) and of narrow ribbons sewed perpendicular to the skirt and the horizontal ribbons (vertical ribbons). The horizontal ribbons are the main drag generators, whereas the narrow vertical ribbons serve only to space and control the horizontal ribbons. The gores are interconnected by radial ribbons which extend from vent to skirt and overlap the horizontal ribbons of two adjoining gores. The filling time of this canopy type may be extended by increasing the spacing of the vertical ribbons. This will also reduce the opening shock appreciably. Variation in the spacing of the horizontal ribbons will affect total porosity of the drag producing surface and, consequently, stability. Total porosity includes both geometrical and mechanical porosity, the former being produced by ribbon spacing, and the latter by weave and composition of the ribbon itself. Varying total porosities are required for FIST type canopies of varying diameter and for different applications. In general, as the diameter increases, the total porosity must decrease in order to achieve a constant drag coefficient, constant stability, and relatively constant opening characteristics. Figure 5-3-15 shows the relationship between total porosity λ_t, various canopy diameters, and different applications.

Distance between the vertical ribbons is generally determined by the filling time required for the canopy to obtain a certain opening shock, or a certain minimum altitude loss during inflation, or both. The following vertical ribbon spacings are recommended:

a. 5 - 6 inches, without center vertical ribbon for parachute canopies of low opening shock.

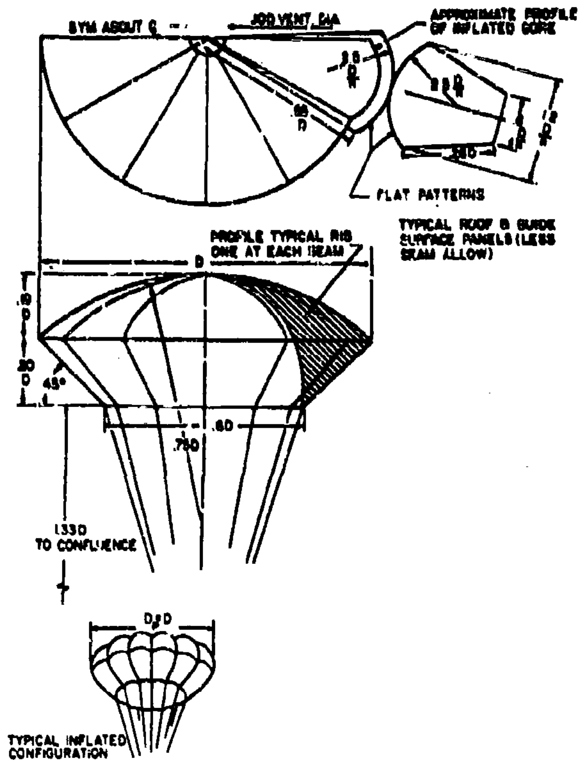


Figure 5-3-9. Ribbed Guide Surface Type Parachute Canopy

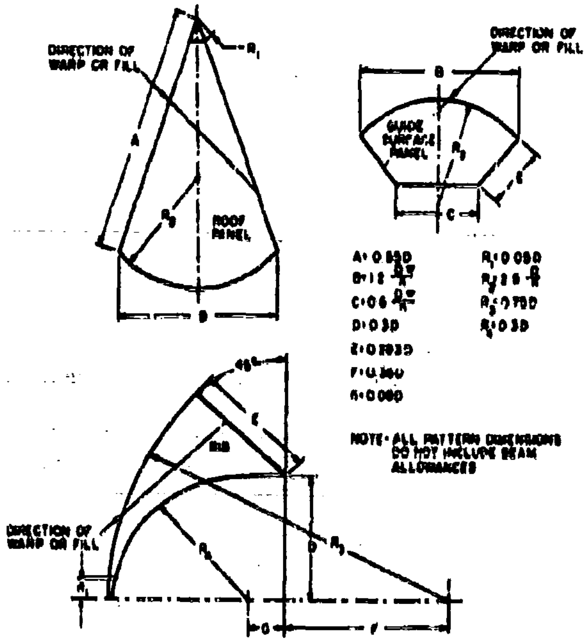


Figure 5-3-10. Layout for Roof Panel, Guide Surface Panel, and Rib for Stabilization Type Ribbed Guide Surface Parachute Canopy

b. 4 - 6 inches, for parachute canopies used for aircraft approach and aircraft deceleration application.

c. 2 - 4 inches, for parachute canopies required to open rapidly at low altitudes.

For porosity calculations, the influence of ribbon porosity must be taken into consideration, if porous ribbons are used. The total porosity of the drag producing surface λ_t is expressed in percent and is determined from the ratio of the porous area (including ribbon porosity) of the drag producing surface to the total drag producing surface area. Normally, mechanical, or ribbon, porosity λ_m is expressed in cubic feet of air forced through a square foot of ribbon in one minute at a pressure of 0.5 inches of water. A ribbon porosity of 27.4 cu. ft./sq. ft./min. is equivalent to a geometric porosity of one percent. Therefore, mechanical porosity λ_m may be expressed in percentage after division of actual porosity by 27.4. Geometric porosity λ_g, also determined in percent, is the ratio of that area of the drag producing surface not covered by ribbons to the total drag producing surface area. The required geometric porosity of a FIST type canopy may therefore be expressed as

$$\lambda_g = \lambda_t - \frac{\lambda_m}{27.4}$$

If it is assumed that the total area of the drag producing surface is a ribbon grid from which one element may be separated, the geometrical porosity of the grid may be expressed as

$$\lambda_{ga} = \frac{a_{VR}\, b_{HR}}{(a_{VR} + A_{VR})\,(b_{HR} + B_{HR})} \cdot 100\ [\%]$$

A ribbon grid element is shown in Figure 5-3-16. The geometrical grid porosity is increased by the vent opening and decreased by the practically impermeable radial ribbons and the horizontal ribbons at the apex. The vent itself should not be more than one percent of the total area of the drag producing surface, if porosity calculations are to be correct. Primarily, the purpose of porosity calculations is the determination of the spacing of horizontal ribbons on the basis of given factors such as canopy diameter D, vent opening d_v, number of gores n, ribbon widths A_{VR} and B_{HR}, and

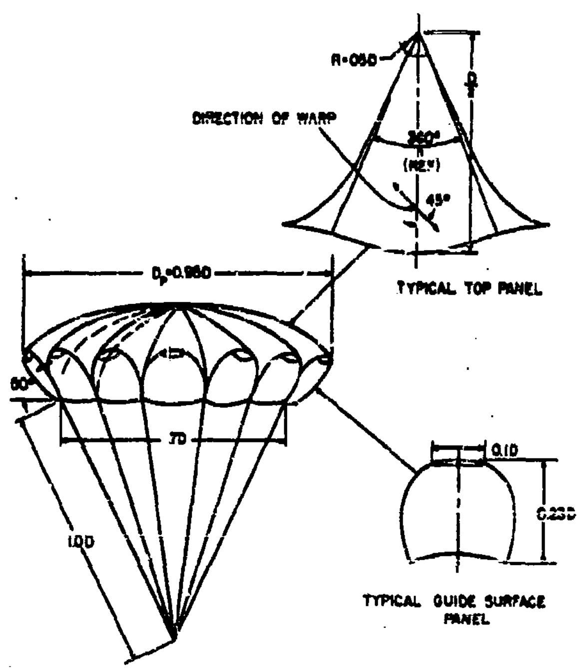
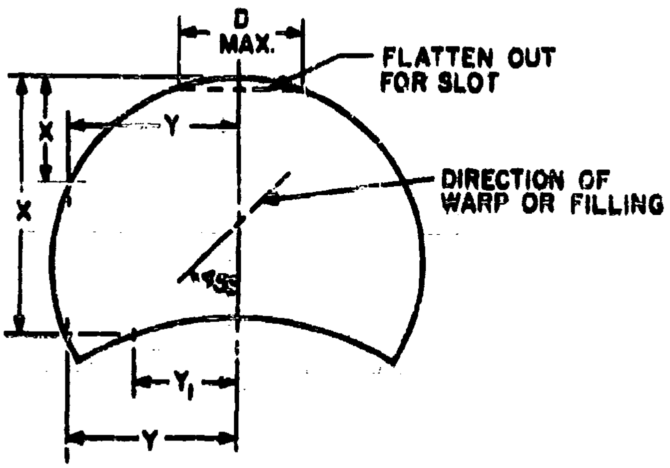


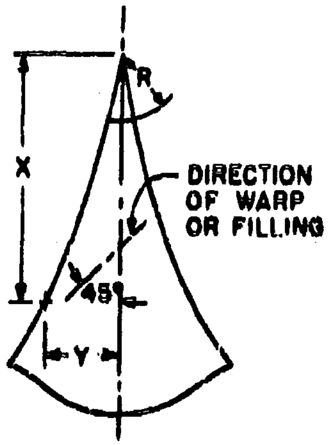
Figure 5-3-11. Ribless Guide Surface Type Parachute Canopy

GUIDE SURFACE PATTERN



NUMBER OF PANELS-12 AND 16
SEAM ALLOWANCE NOT INCLUDED
ONE SLOT IN EACH PANEL
0.1 D MAX. WIDE (IF REQUIRED)

ROOF PATTERN



NUMBER OF PANELS-12 AND 16
SEAM ALLOWANCE NOT INCLUDED

GUIDE SURFACE PATTERN $X_0 = 0.23$ D MAX.

X/X_0	.05	.10	.15	.20	.30	.40	.50	.60	.70	.80	.90	.93	.95	1.00
Y/X	4.33	3.21	2.58	2.13	1.58	1.25	1.03	.86	.722	.61	.515	.491 .000	.472 .226	.430

12 PANELS ROOF PATTERN $X_0 = 0.50$ D MAX.

X/X_0	.10	.15	.20	.30	.40	.50	.60	.70	.80	.875	.90	.95	.975	1.0
Y/X	.394	.394	.394	.407	.410	.416	.428	.441	.495	.676	.527	.261	.1625	0.0

GUIDE SURFACE PATTERN $X_0 = 0.23$ D MAX.

X/X_0	0.05	0.10	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.944	0.95	1.00
Y/X	3.85	2.77	2.18	1.82	1.37	1.075	0.882	0.729	0.615	0.517	0.43	0.397 0.000	0.394 0.0896	0.358

16 PANELS ROOF PATTERN $X_0 = 0.50$ D MAX.

X/X_0	0.10	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.888	0.90	0.95	0.975	1.0
Y/X	0.303	.3045	.305	.307	.311	.317	.336	.366	.434	.622	.554	.261	.1625	0.0

Figure 5-3-12. Pattern Dimension Factors for 12 and 16 Gore Ribless Guide Surface Type Parachute Canopies

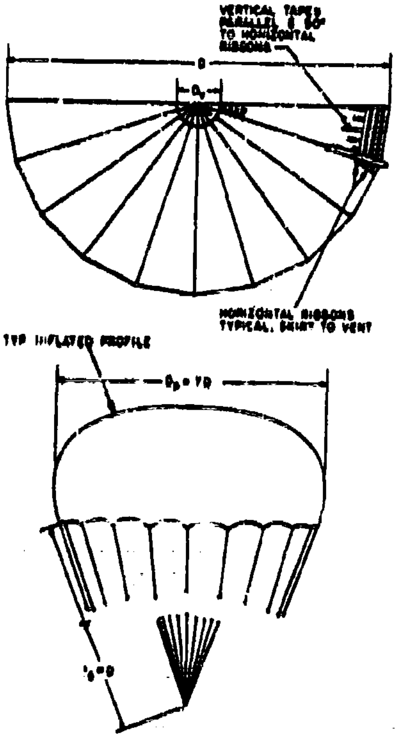


Figure 5-3-13. FIST Ribbon Type Parachute Canopy

the spacing a_{VR} of the vertical ribbons. In order to determine porosity, the following general sequence is recommended.

The required total porosity λ_t for the drag producing surface is determined from Figure 5-3-15. Utilizing the data contained in Section 5 of this chapter, which gives the mechanical porosity λ_m of ribbons recommended for use, the required geometrical porosity is determined from

$$\lambda_g = \lambda_t - \frac{\lambda_m}{27.4}$$

Knowing the required geometrical porosity λ_g, a correction factor for the diameter of the drag producing surface required should be obtained from Figure 5-3-17. The value for λ_a should be added to the value for λ_g to compensate for the loss of porosity effected by the radial ribbons and vent ribbons, and to correct for the increased porosity obtained from the vent. From the new data, $\lambda_{g_a} = \lambda_g + \lambda_a$, the actual geometrical porosity may be converted into ribbon spacing by use of Figure 5-3-18, in which various possible spacings of vertical ribbons and horizontal ribbons are plotted against geometric porosity. The factor λ_{g_a} is grid porosity, actually, and indicates what the porosity λ_g of the ribbon grid should be to compensate for the impermeability of the radial and lateral bands. Following determination of ribbon spacing, the remainder of the drag producing surface design may be completed. It will be found that, once the width and spacing of horizontal ribbons are known, the gore dimensions may vary from the ideal dimensions because the addition or subtraction of one ribbon may not provide the planned diameter or vent size. After the above data have been determined, it is recommended that the actual geometric porosity $\lambda_{g_{act.}}$ be checked as outlined below

$$\lambda_{g_{act.}} = \lambda_{g_a} + \left[\frac{S_o}{S_o}\,(100 - \lambda_{g_a})\right] - \left[\left(\frac{S_{RR} + S_{VR}}{S_o}\right)\lambda_{g_a}\right] \text{(Percent)}$$

$$\lambda_{g_{act.}} = \lambda_{g_a}\left[1 - \frac{2\,B_{HR}\left(1 - \frac{d_v}{D_o}\right)}{\pi_o D_o}\right] + \left[\left(\frac{d_v}{D_o}\right)^2 (100 - \lambda_{g_a})\right] \text{(Percent)}$$

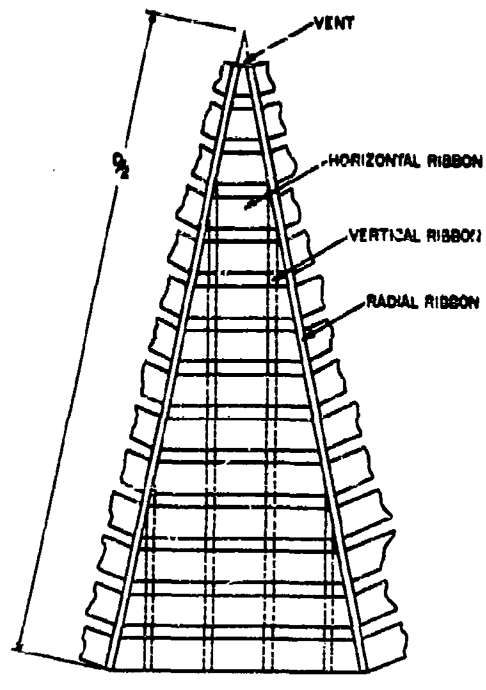


Figure 5-3-14. Core Construction of a FIST Ribbon Type Parachute Canopy

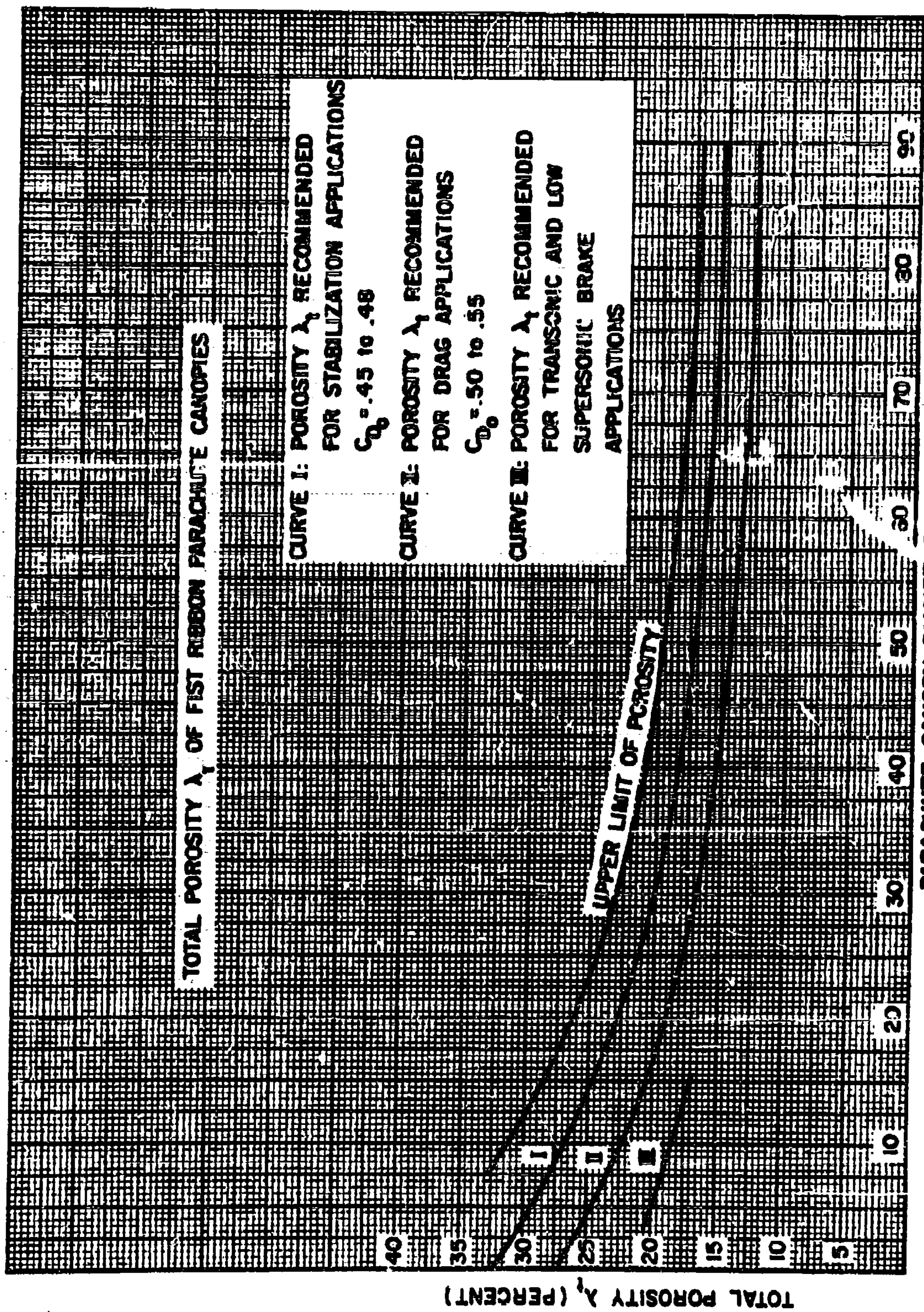


Figure 5-3-15. Relationship Between Total Porosity λ_t, Canopy Diameter and Different Applications

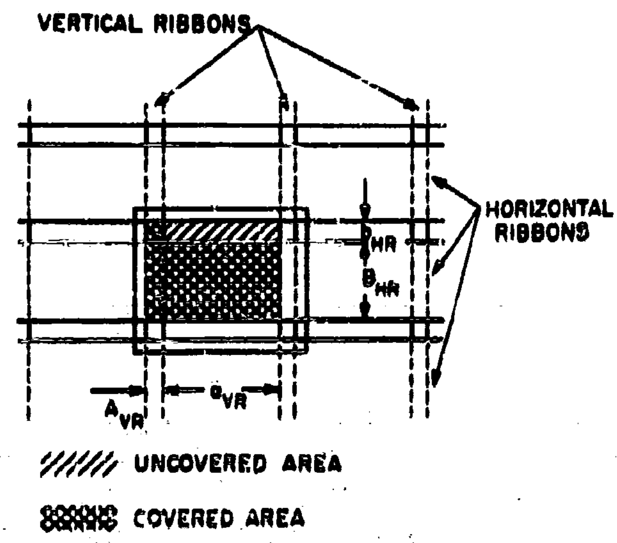


Figure 5-3-16. Ribbon Grid Element

wherein λ_{g_a} = Ribbon grid porosity required for the drag producing surface, assuming the whole canopy is constructed of the grid (percent)

S_{RR} = Total area covered by radial ribbons

S_{VR} - Total area of horizontal ribbons at the vent, not covered by radial ribbons

η_0 = Polygon shape factor; see tabulation, paragraph 3.2.5.

In order not to endanger canopy inflation, the use of pocket bands is recommended. Use of pocket bands raises the critical porosity of a FIST type canopy between 8 and 10%. Figure 5-3-19 shows the general configuration of the pocket bands and values for the free length L_a of the pocket band for any given number of suspension lines. Strength of the pocket bands should always be at least 50% of that of the suspension line used.

3.2.11 RING SLOT TYPE CANOPY. The drag producing surface of a ring slot canopy consists of polygonal cloth rings joined together by radial tapes to provide open spaces or slots between rings. The planform and inflated shape of a typical ring slot type canopy is shown in Figure 5-3-20. A typical gore of a four-slotted ring slot parachute canopy is shown in Fig-

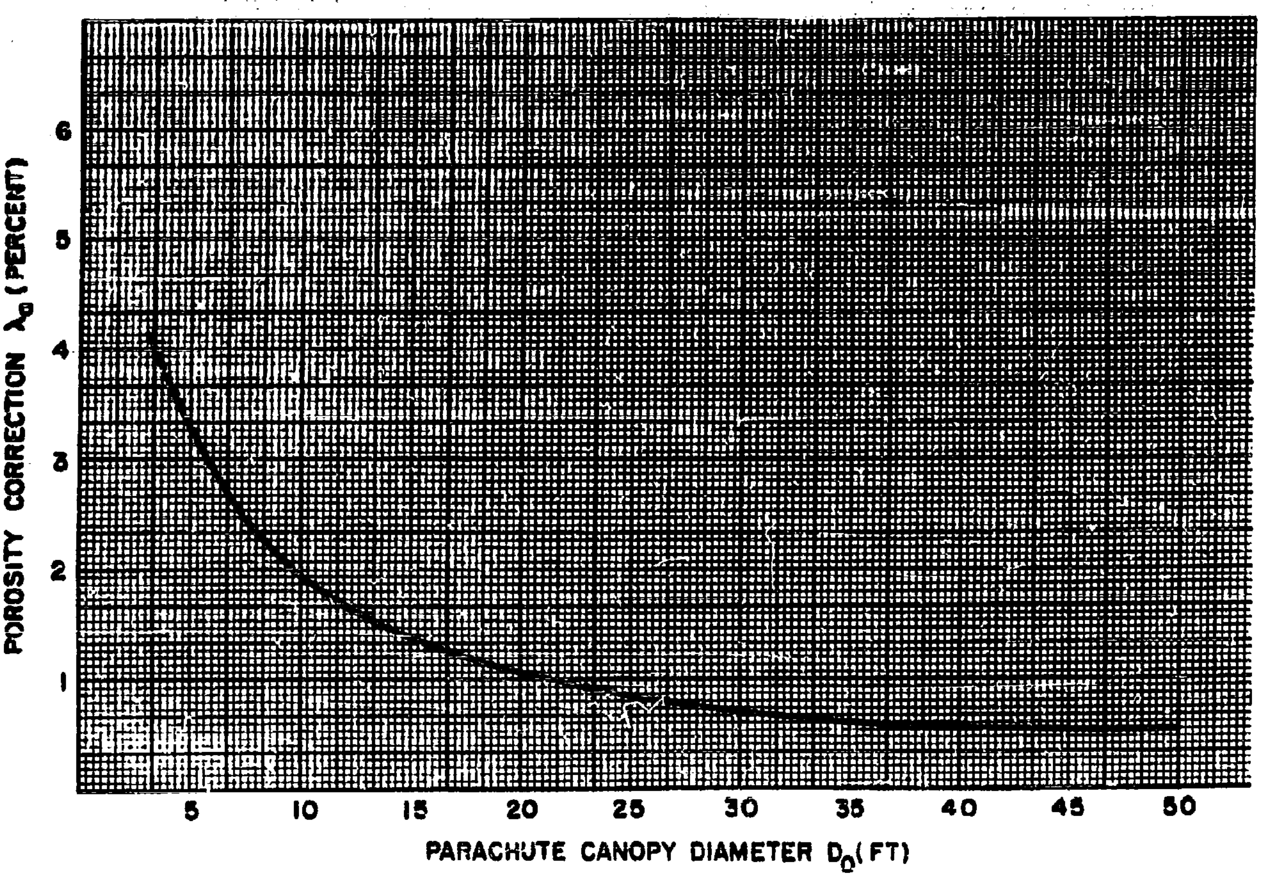


Figure 5-3-17. Porosity Correction λ_a Versus Diameter of the Drag Producing Surface

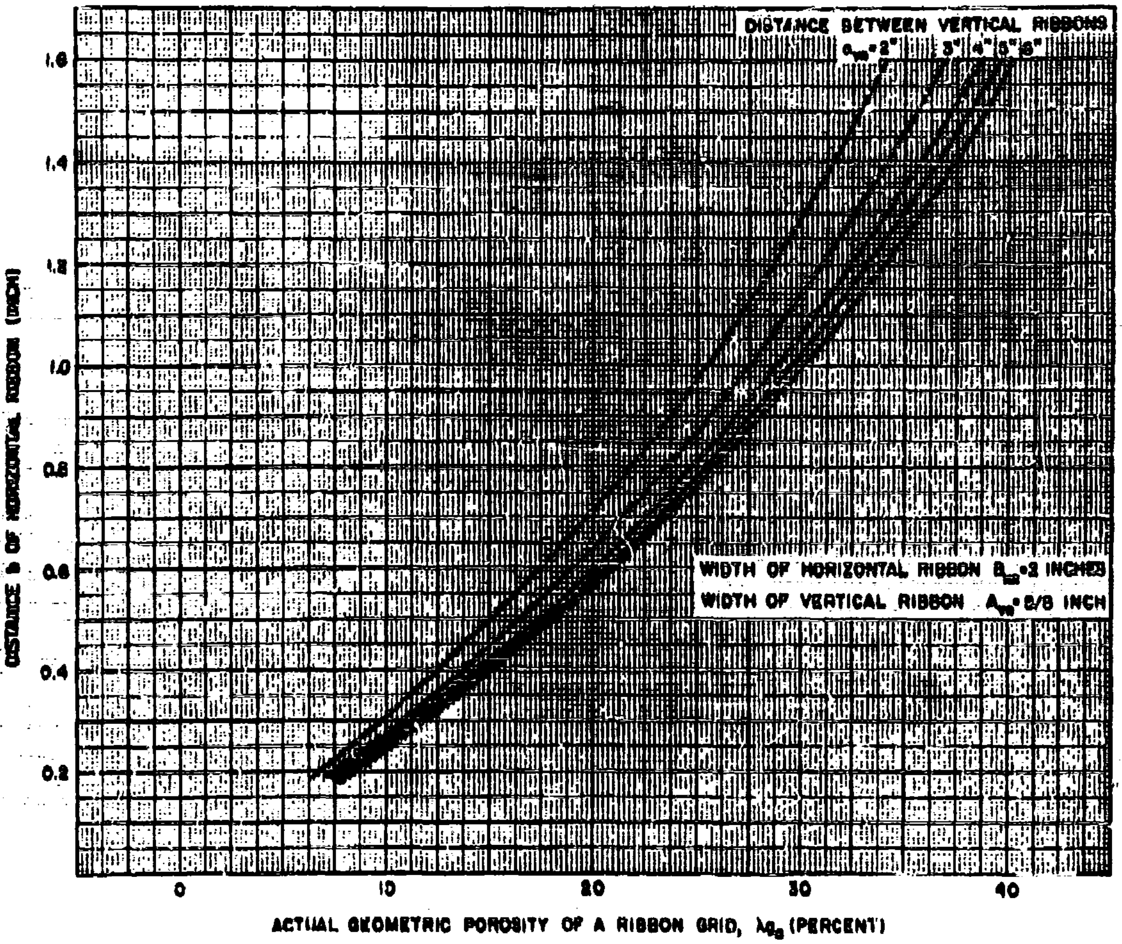


Figure 5-3-18. Actual Geometric Porosity λ_{g_a} of a Ribbon Grid Versus Distance of Horizontal and Vertical Ribbon

ure 5-3-21, with the principle component parts and dimensions indicated. The selection of total porosity of the drag producing surface is, as for the FIST type canopy, dependent on the stability and opening characteristics required. The range of recommended total porosity for the drag producing surface is shown in Figure 5-3-22. Geometric porosity, the major component of total porosity, is the ratio of total slot and vent areas to the total canopy area. Even distribution of the geometric porosity is an important factor. Tests have shown that slots equally spaced between vent and skirt produce the most satisfactory results. The total slot area of the drag producing surface may be determined by

$$S_\lambda = \lambda_g S_o - s_o$$

wherein S_λ = total slot area in square feet
λ_g = Geometric porosity expressed as a decimal.

Dividing this total slot area by the number of gores results in the slot area required for each gore. The design problem then requires balancing the number and height of the cloth sections and the slot width to obtain the required diameters and slot area. The cloth sections are cut in the form of trapezoids, with the warp of the cloth parallel to the parallel sides. Although the section height may be any value desired, the cloth yardage is most efficiently used if cut into quarters, thirds, halves, or used in full width. Vertical ribbons, sometimes called vertical tapes, are usually placed from the vent to the skirt, down the center of each gore. Pocket bands perform the same function on ring slot parachute canopies as on FIST ribbon parachute canopies. Dimensions for pocket band design may be obtained from Figure 5-3-19. In other respects, design of this canopy is similar to that of the FIST ribbon canopy.

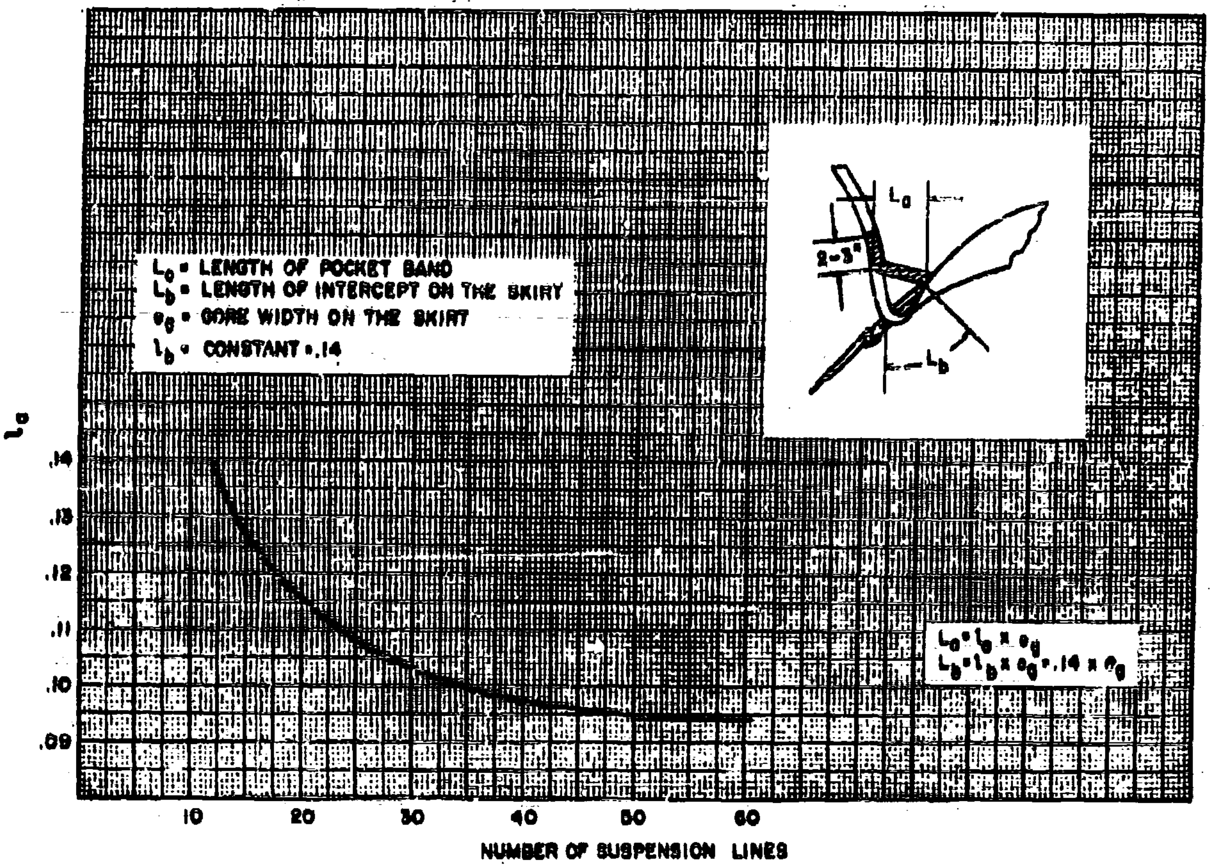


Figure 5-3-19. Pocket Band Design for Flat Parachute Canopies

3.3 VOLUME AND WEIGHT OF PARACHUTE CANOPIES.

Volume and weight of parachute canopies can be calculated from the dimensions of a known canopy design, provided the weights and volumes of the materials used are known. For convenience, the curves shown in Figures 5-3-23 through 5-3-29 have been plotted to show volume and weight of different parachute canopy types. These curves are based upon a balanced relationship between canopy material and suspension lines as outlined in paragraph 3.2.1.1.

3.4 RISERS.

The riser system is commonly composed of one or more members of heavy webbing which extend between the lower end of the suspension line system and the load, and of such metal interconnection fittings as may be required. Since the individual webbing members are considered parallel while under load, the maximum load carried is simply the drag load, which again is usually considered as the opening shock load. The general equation for the load on each riser is then

$$F_R = \frac{F_o \cdot j}{Z_R \cdot u \cdot o \cdot e \cdot k}$$

wherein F_o = maximum opening force
j = safety factor
Z_R = number of individual webbings
u = factor involving the strength loss at the connection loops
o = factor related to strength loss in material from water and water vapor absorption
e = factor related to strength loss by abrasion
K = factor related to strength loss by fatigue

Actual values for these factors may be obtained from the tabulation in paragraph 3.2.4.

The weakest point in the riser system is generally not the webbing itself but the junctions with other parts of the assembly. The prevailing type of joint is one in which the webbing is looped around a circular bar of some form of hardware and sewed to itself. The diameter

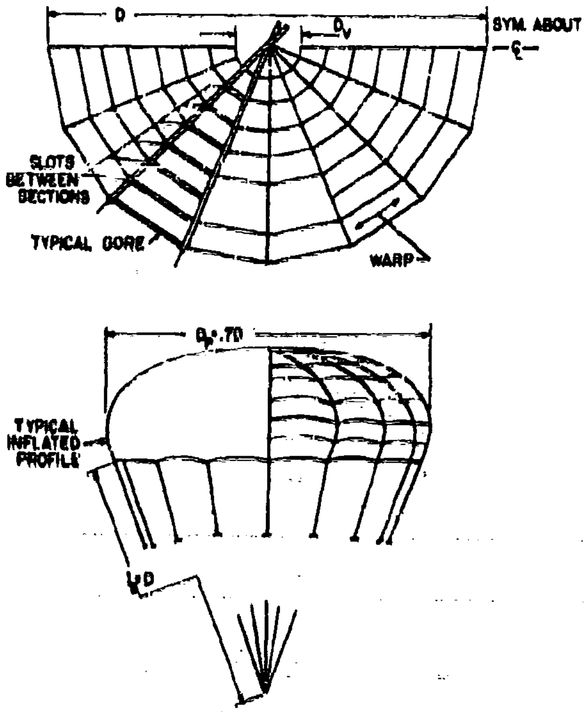


Figure 5-3-20. Ring slot Type Parachute Canopy

of the metal link has been found to have an effect on the efficiency of the joint. In general, the efficiency decreases as the bolt diameter decreases. The efficiency of various 3,000-lb. webbing loops as affected by the bolt diameter is graphically presented in Figure 5-3-30.

3.5 KEEPER.

The necessity for, and advantages of, utilizing a keeper in the suspension line or riser system can be described briefly as an integral unit required in the system to maintain the desired suspension line length to diameter (l_s/D_o) ratio for optimum parachute canopy performance and reinforcement of the line confluence point. The keeper material generally consists of the same type of material of which the riser is made; however, it has a lower rated strength. The strength of the keeper material will depend upon the construction and application of the riser. For a majority of applications, a keeper material having approximately 30% of the rated strength of the individual riser webbings is considered sufficient. The keeper is constructed by wrapping the webbing around the riser webbings at least 2-1/2 turns and then stitching it to the riser proper. For first stage missile recovery applications, and other applications in which the suspension lines are extended beyond the confluence point to form the riser, a different type of keeper is required. A typical keeper for first stage missile recovery applications is shown in Figure 5-3-31. This arrangement of keeper and suspension lines provides for a generally equalized distribution of the loads being transferred from the drag producing surface through the lines and minimizes elongation differences due to unsymmetrical canopy loading. Most significant, perhaps, is the total elimination of relative motion between keeper and lines, which has often been found to be the initial cause of line failure due to subsequent friction heating and material crystallization.

3.6 DEPLOYMENT BAGS.

3.6.1 GENERAL. Since a multitude of different types are known to exist, and since there are limitless variations within types, no general description of deployment bags in terms of size or shape can be attempted. Deployment bags may, however, be described in terms of functions, namely:

a. Deployment bags primarily contain the drag producing surface of a canopy; they may or may not provide stowage positions for the suspension lines.

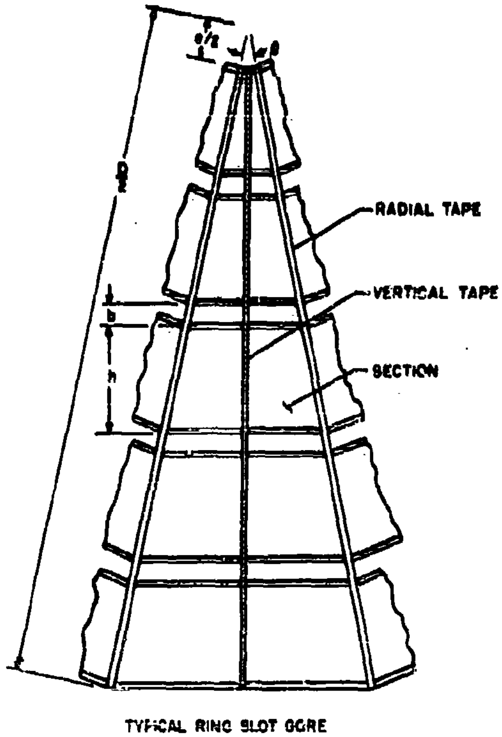


Figure 5-3-21. Core Construction of a Ring slot Type Parachute Canopy

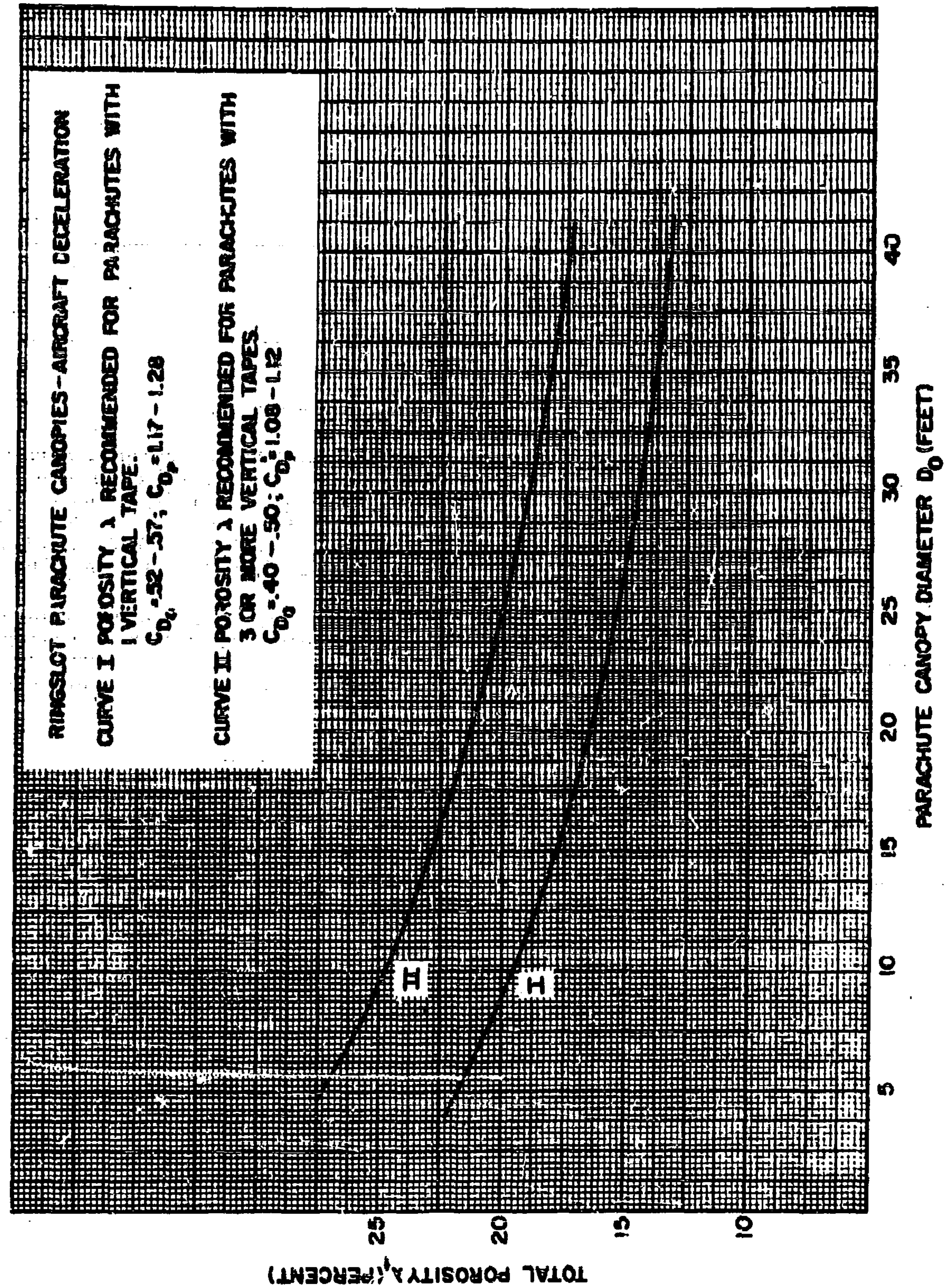


Figure 5-3-22. Relationship Between Total Porosity λ_p Canopy Diameter, D_0, and Different Applications

b. Deployment bags control the sequential operations of deployment by means of a closure or control method which locks the canopy in the bag, and which may depend for operation upon line deployment, pilot chute drag, snatch force, or operation of a mechanical device.

In general, little difficulty will be encountered in shaping a deployment bag to the space available. Space, however, definitely affects the line placement and closure methods used.

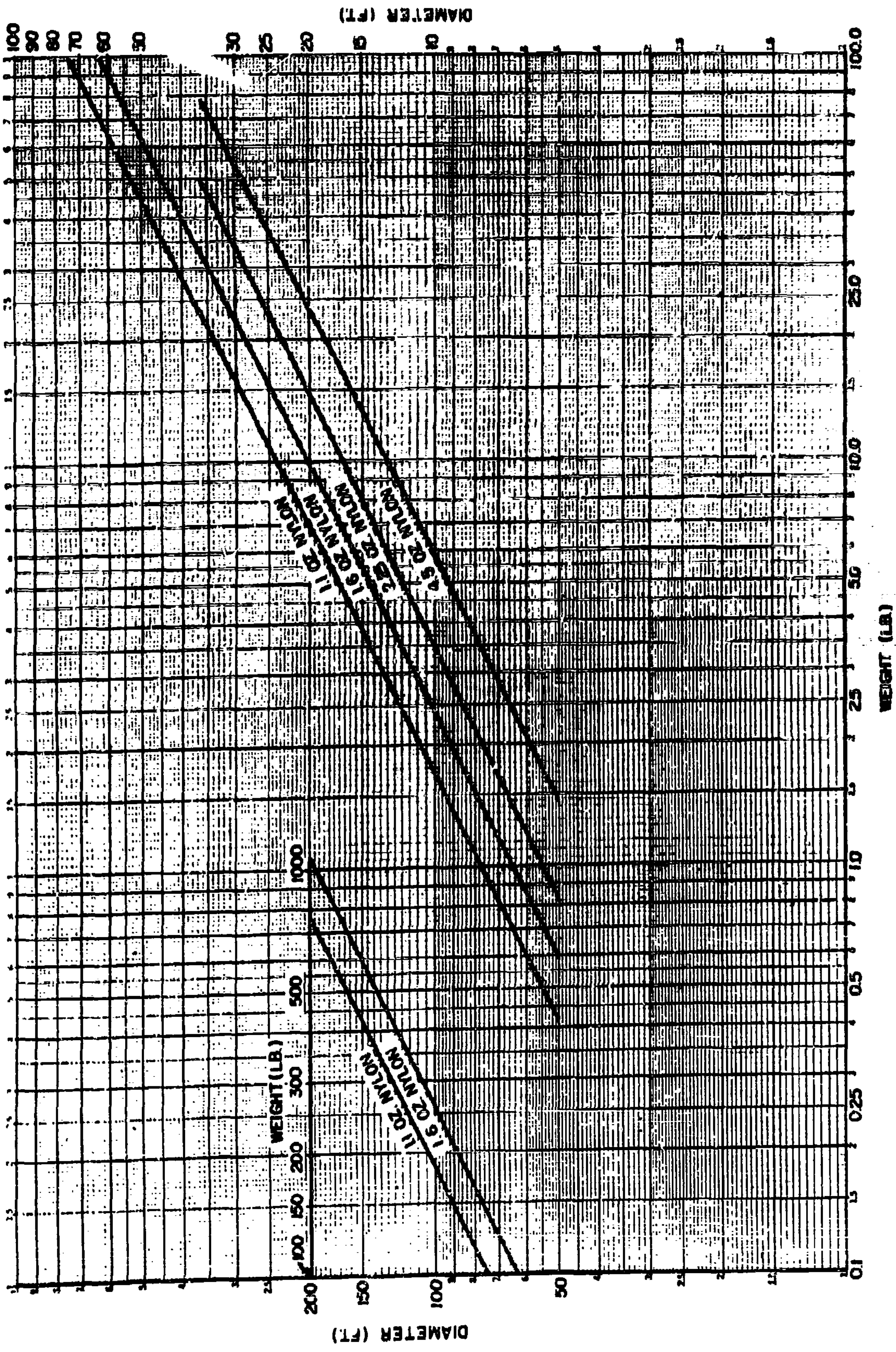
5.6.2 DEPLOYMENT BAG DESIGN. Deployment bag design may be divided into two general groups: methods used for stowage and placement of the suspension lines, and methods used for control and operation of canopy mouth closure. The chief considerations in detailed design of bags are bag strength and smooth working surfaces. Deployment bags must be able to contain and control the canopy throughout the two most difficult conditions of deployment. These conditions arise at lift-off, or ejection, of the deployment bag by a static line, pilot chute, or ejection device, and at the opening of the bag for release of the parachute canopy. Smooth working surfaces are required in all areas of the bag adjacent to the drag producing surface during deployment, and in the area adjacent to the suspension lines. The basic enclosure for the canopy, whatever its shape, should, if possible, be sufficiently tight to prevent extensive movement of the canopy within the bag during high accelerations encountered during lift-off or ejection. If bags are undersize or require extreme effort to close, however, friction burns on the canopy are probable. A well-designed bag will allow the canopy to be extracted manually with very little effort once the bag closure is opened. Further compression of the bag for packing purposes may be accomplished within the pack or container itself, since the materials and construction of the bag render it less sensitive to frictional damage than the canopy.

Normal layout and cutting methods are used in the construction of bags. The basic container is usually formed in one of three shapes, cylindrical, trapezoidal, or cubical, in a manner to obtain maximum strength from the material along the longitudinal axis of the bag. Wherever possible, seams should be faced away from the areas adjacent to the canopy.

Most reinforcing webbings should be added to the basic container before sewing the container in its final shape. In general, two basic systems of webbing reinforcement are used, depending upon the forces involved in the use of the deployment bag. For personnel parachutes and light aerial delivery parachute applications, straight-through reinforcement is normally used. Figure 5-3-32 shows a view of a basic trapezoidal container with its reinforcement webbings, which also form the bridle for attachment to a static line or pilot chute. Cylindrical bags may be formed in the same manner, as shown in Figure 5-3-33, using whatever number of longitudinal webs are required to achieve the desired strength. Lateral webs are usually of fairly light materials. On bags for very high speed equipment, however, it may be necessary to provide additional lateral webs to prevent bursting of the basic container. On heavy bags for large parachute canopies or for very high speed use, it is considered good practice to use either X or W longitudinal web design, since much strength is added to the assembly by such construction. In addition, lateral webs should be considerably increased in strength to prevent bursting of the basic container. Figure 5-3-34 shows a typical heavy bag for First Stage Missile Recovery application. Locking loops should be reinforced heavily, since the full weight of the accelerated canopy bears on the locking loop flap and failure of material at this point seriously affects bag performance.

Bags designed for use at high speeds, or for the handling of heavy parachute canopies, are constructed of fairly strong materials. Heavier cotton ducks are suitable for this purpose, but are usually so rough that canopies are badly burned during withdrawal. It is considered good practice to line such bags with cotton material of lighter weight and smoother finish, particularly if the construction and reinforcement of the basic bag have provided a rough interior. Generally, linings are assembled to the bag after the basic container has been cut, and longitudinal webs added.

Bridles are either integral or detachable, depending upon conditions of use. Bags subjected to severe operating conditions, or to constant service, particularly if small and cheap, are equipped with integral bridles. The integral bridle is normally an extension of the main longitudinal reinforcing webs on the bag. Detachable bridles are designed to attach directly to main longitudinal reinforcing webs by suitable hardware. Bridles for large or heavy bags normally provide an effective length, from bag to common connection to the pilot chute bridle line, of at least 75 percent, and preferably


DIAMETER (FT)
WEIGHT (LB.)
4.5 OZ NYLON
2.25 OZ NYLON
1.6 OZ NYLON
1.1 OZ NYLON
1.6 OZ NYLON
1.1 OZ NYLON
WEIGHT (LB.)
DIAMETER (FT)

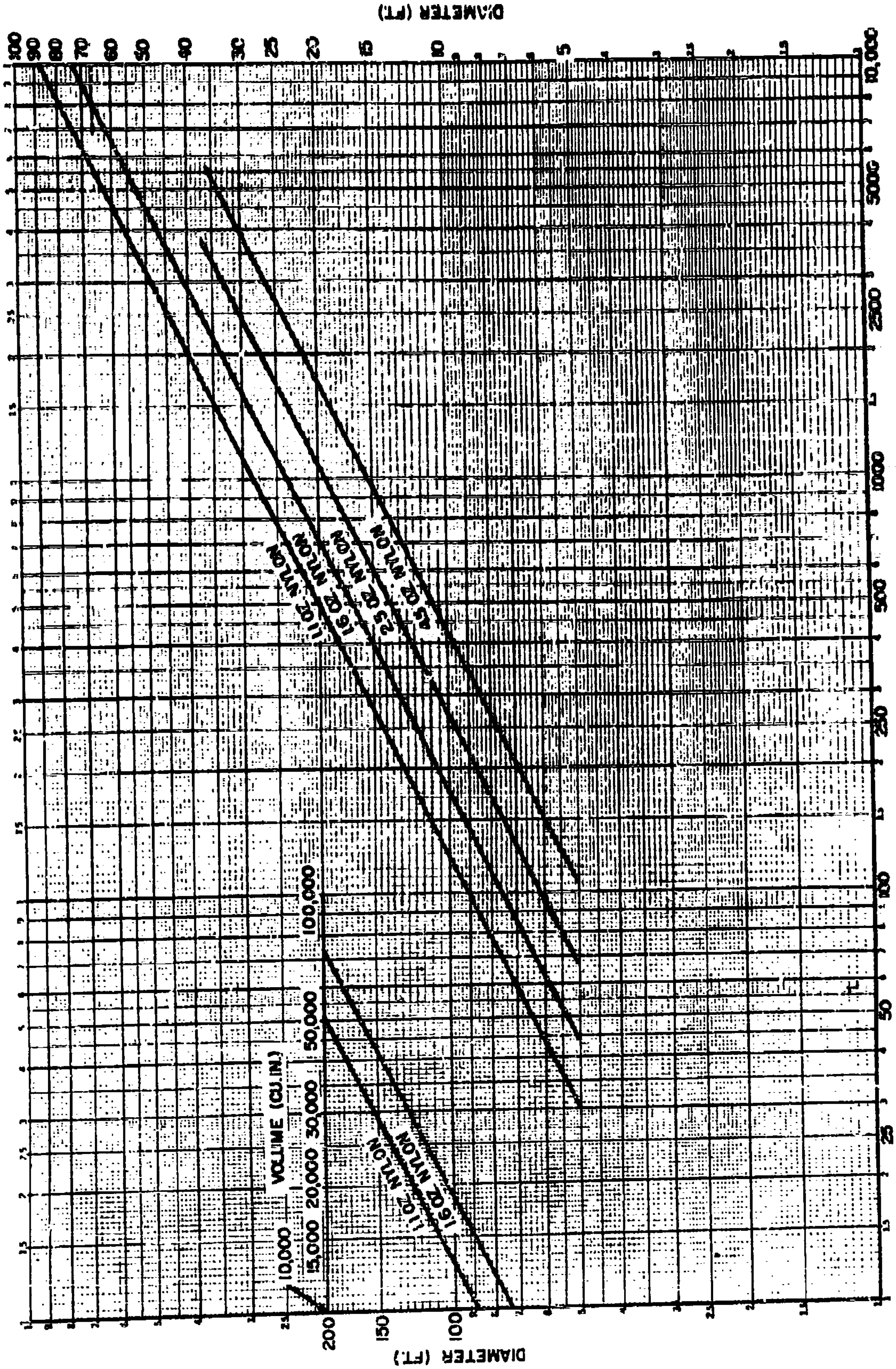
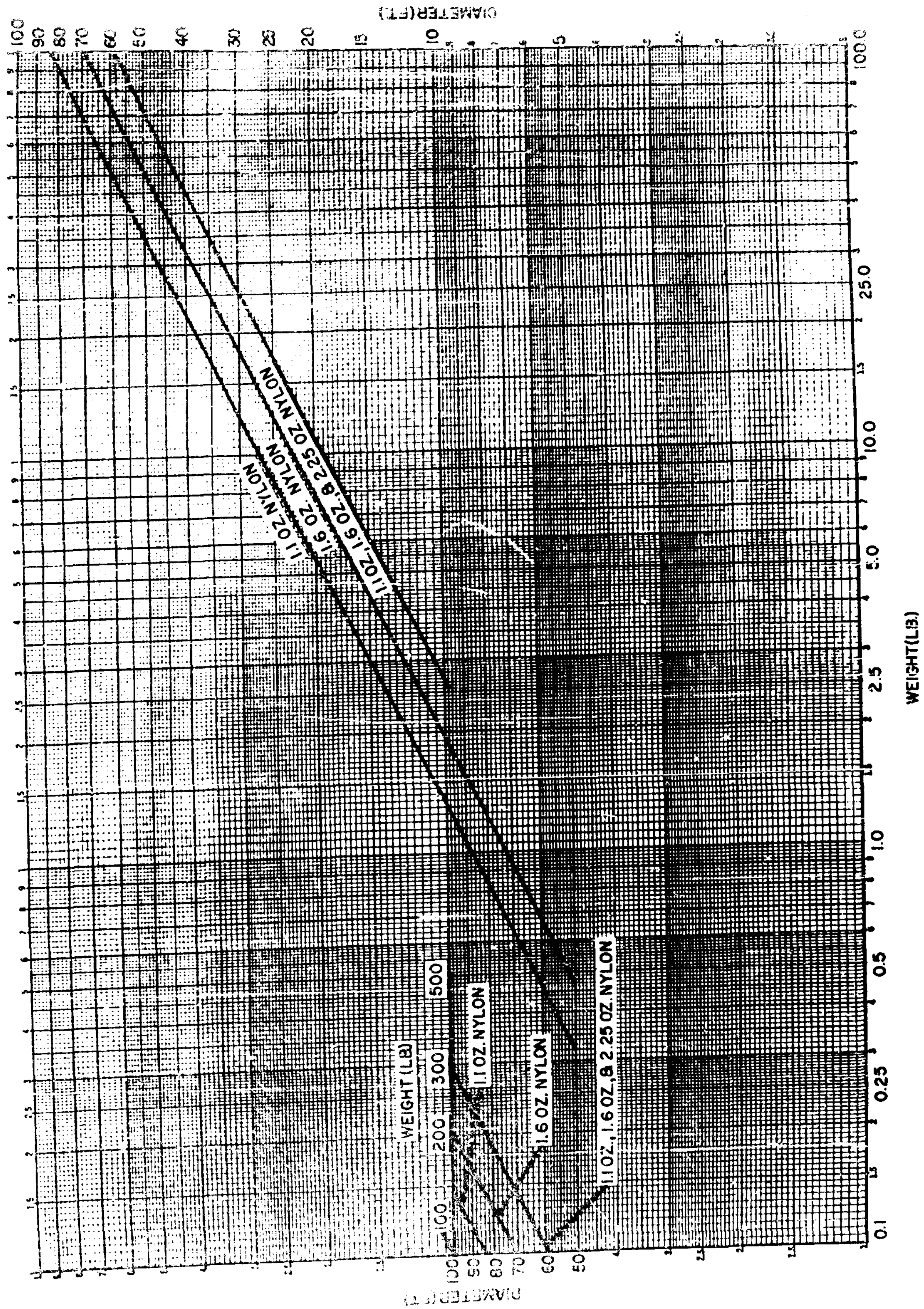


Figure 5-3-23. Weight and Volume, Flat Circular Type Parachute Canopy


DIAMETER (FT)
WEIGHT (LB.)
1.1 OZ. NYLON
1.6 OZ. NYLON
1.1 OZ., 1.6 OZ., & 2.25 OZ. NYLON
WEIGHT (LB)
100
200
300
500
0.1
0.25
0.5
1.0
2.5
5.0
10.0
25.0
100.0

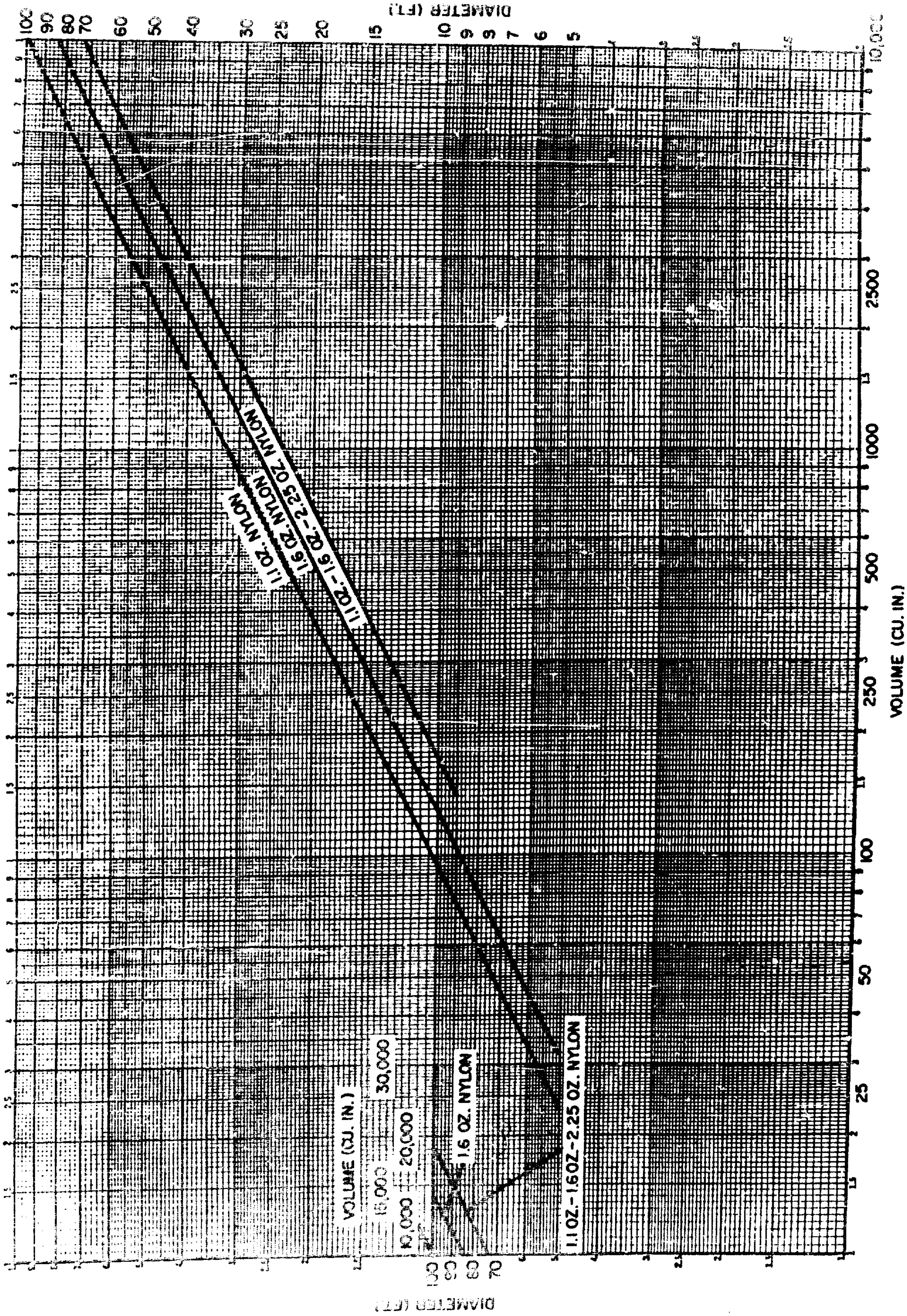
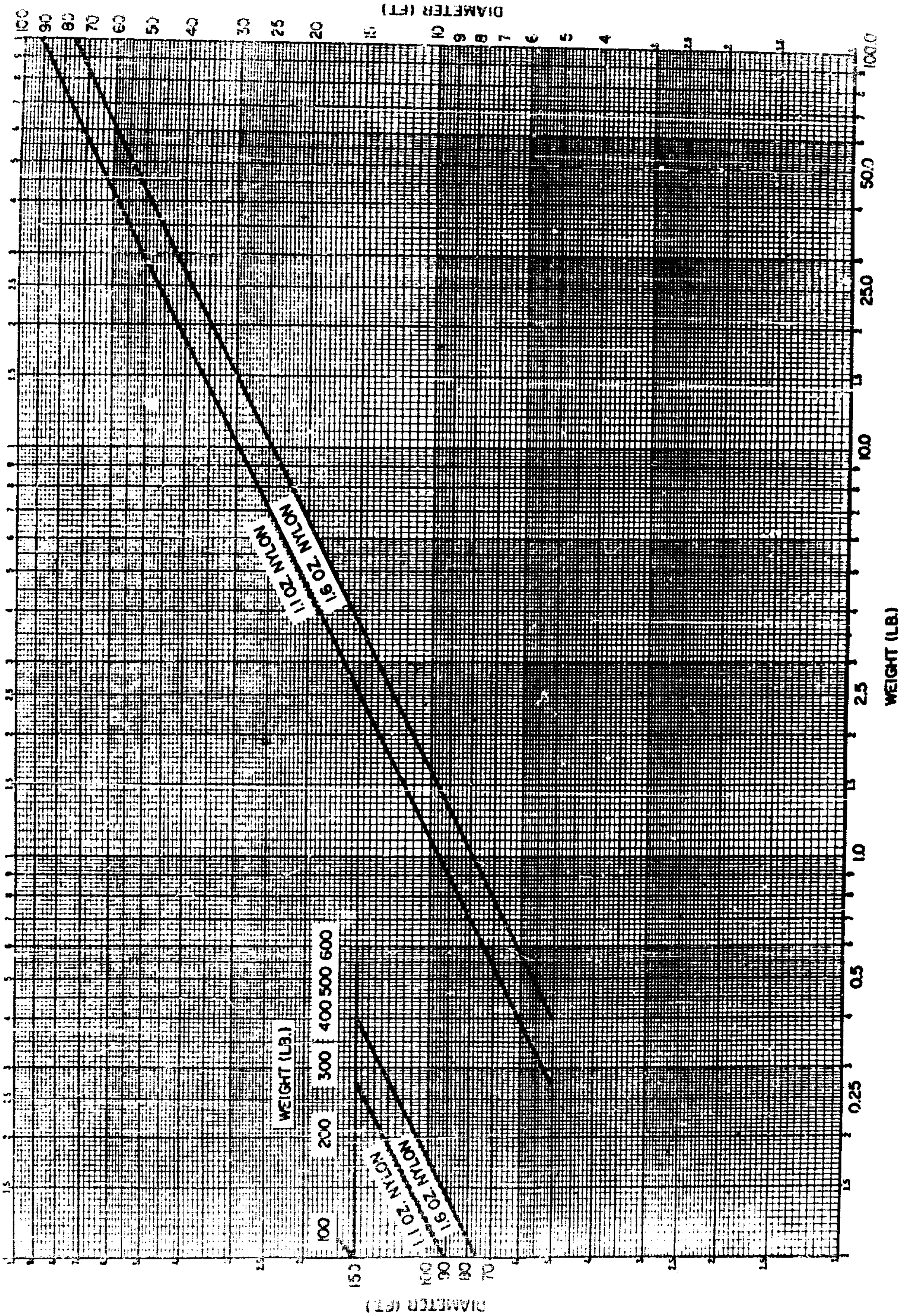


Figure 5-3-24. Weight and Volume, Extended Skirt Type Parachute Canopy


DIAMETER (FT)
WEIGHT (LB.)
1.6 OZ. NYLON
1.1 OZ. NYLON
1.6 OZ. NYLON
1.1 OZ. NYLON
WEIGHT (LB.)
100 200 300 400 500 600
DIAMETER (FT)

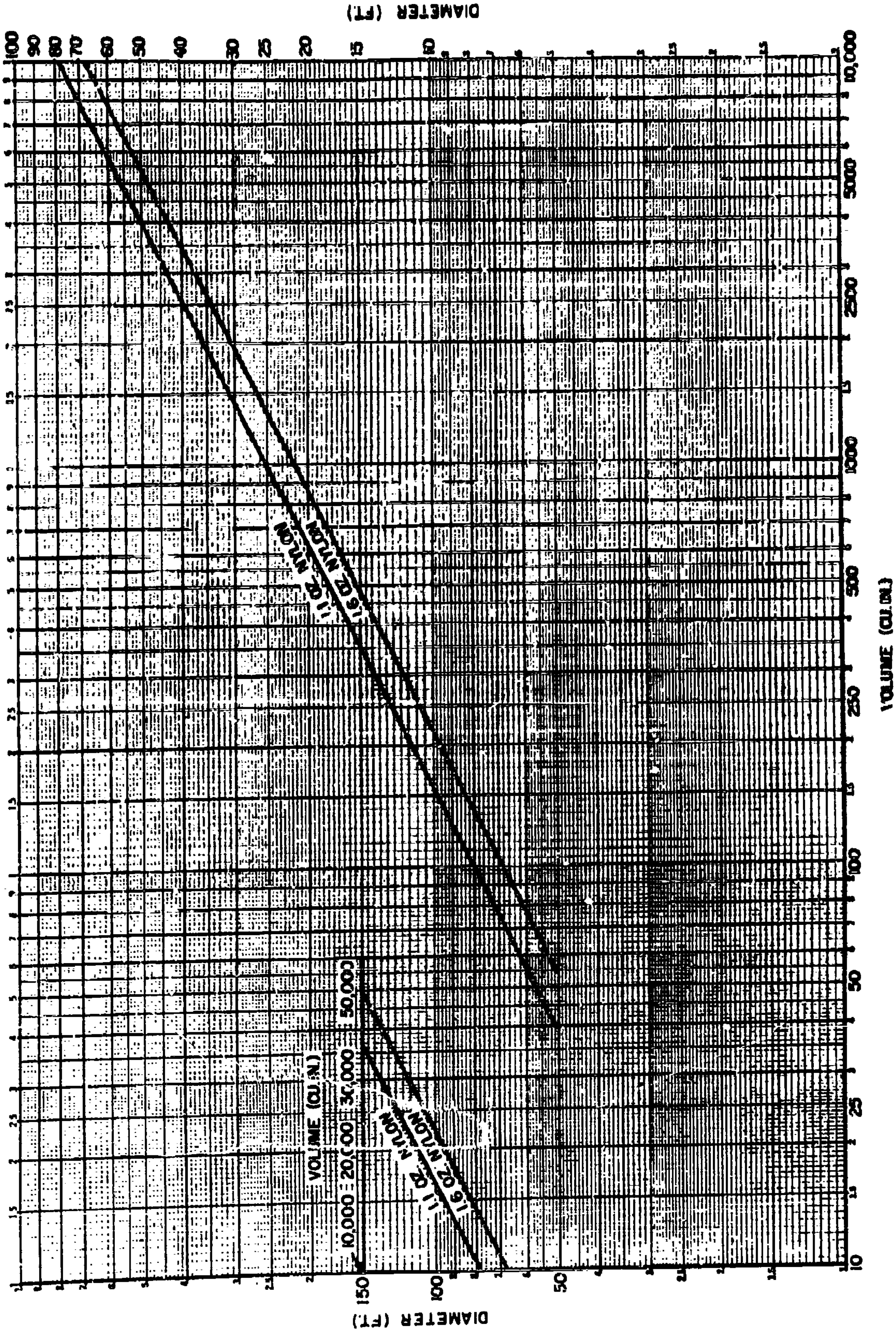
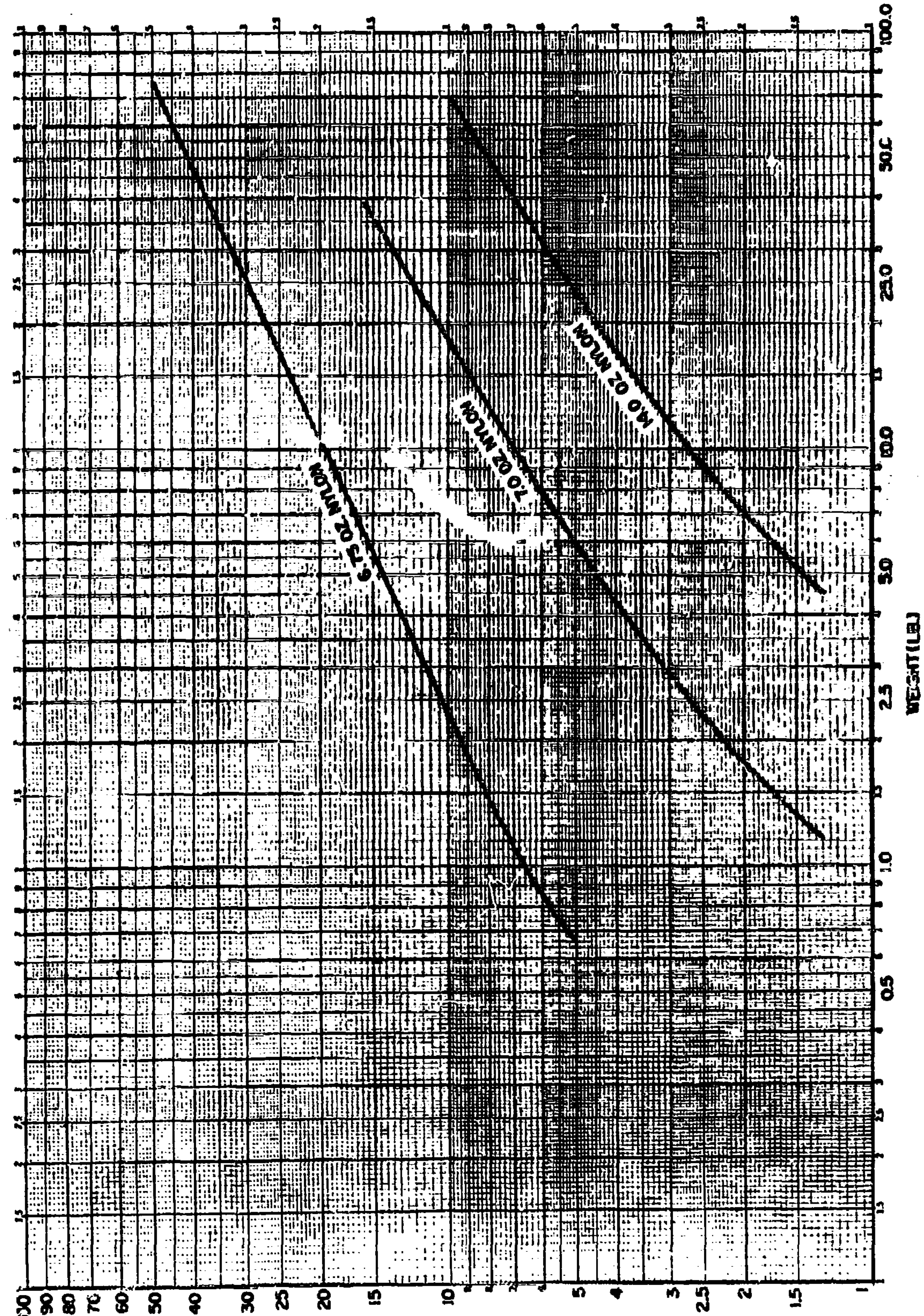


Figure 5-3-25. Weight and Volume, Personnel Guide Surface Type Parachute Canopy


6.75 OZ NYLON
7.0 OZ NYLON
14.0 OZ NYLON
DIAMETER (FT.)
WEIGHT (LB.)
100
90
80
70
60
50
40
30
25
20
15
10
5
4
3
2.5
2
1.5
1
0.5
1.0
2.5
5.0
10.0
25.0
50.0
100.0

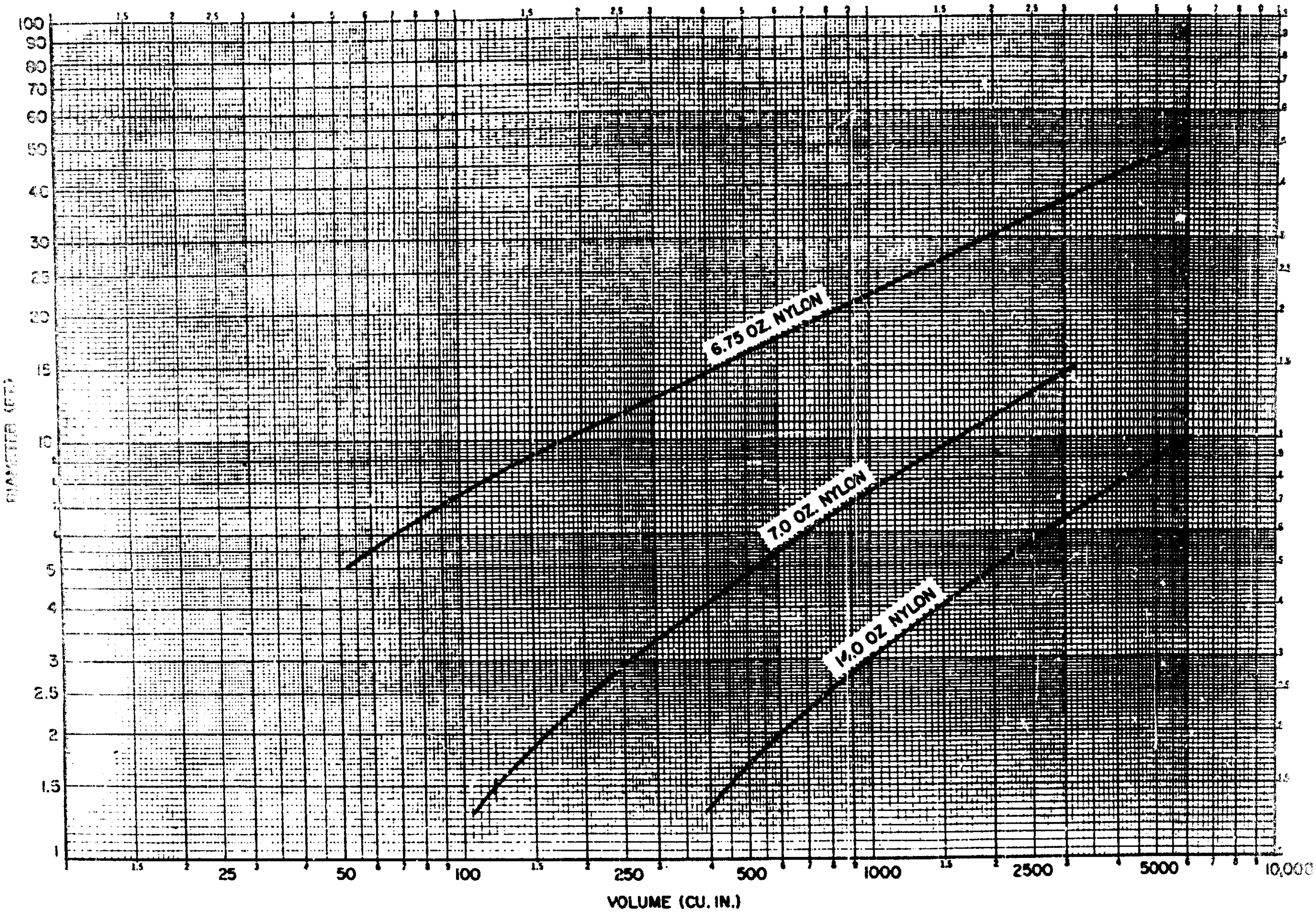
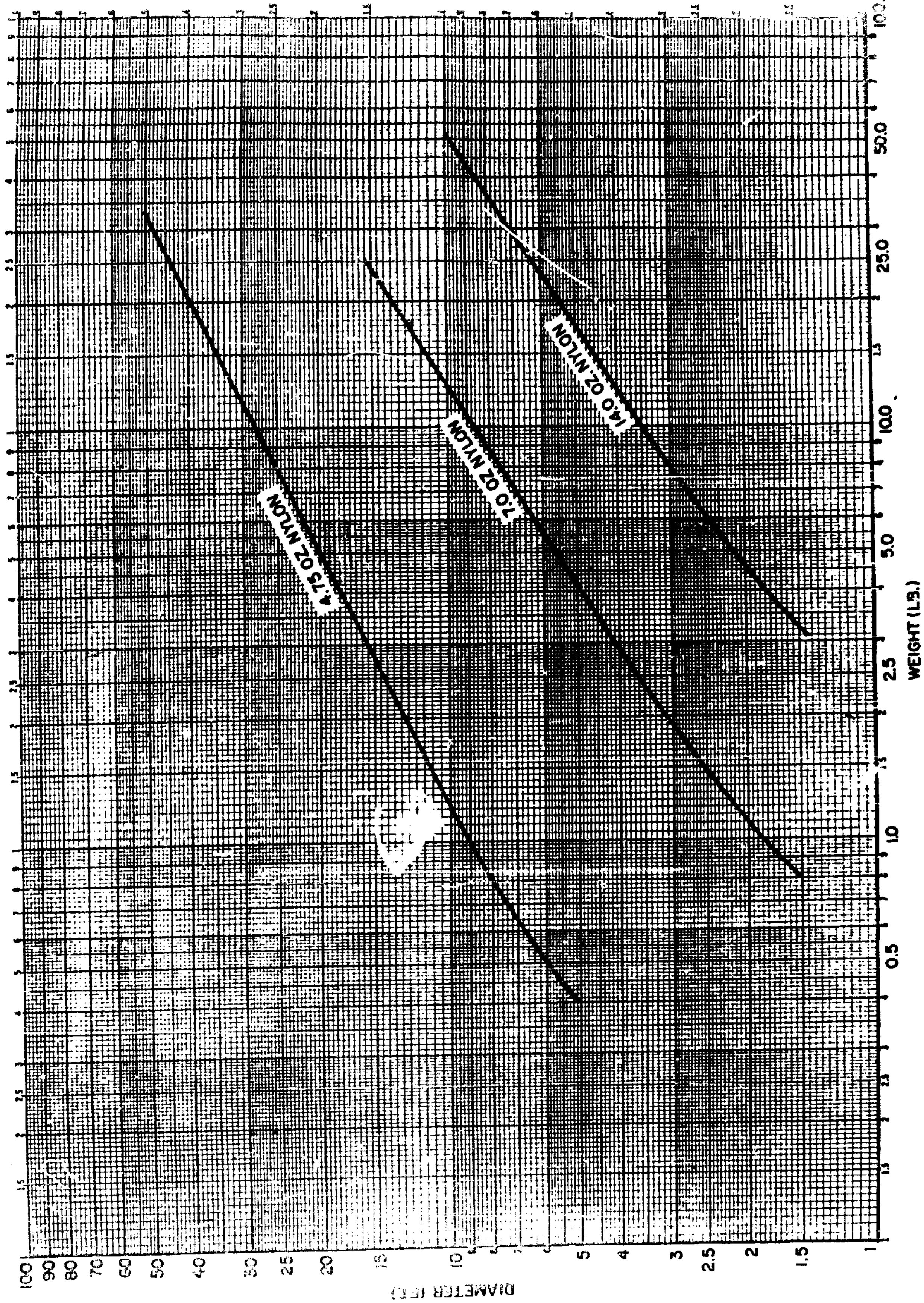


Figure 5-3-26. Weight and Volume, Ribbed Guided Surface Type Parachute Canopy


4.75 OZ NYLON
7.0 OZ NYLON
14.0 OZ. NYLON
WEIGHT (LB.)
0.5
1.0
2.5
5.0
10.0
25.0
50.0
100.0
DIAMETER (FT)
1
1.5
2
2.5
3
4
5
10
15
20
25
30
40
50
60
70
80
90
100

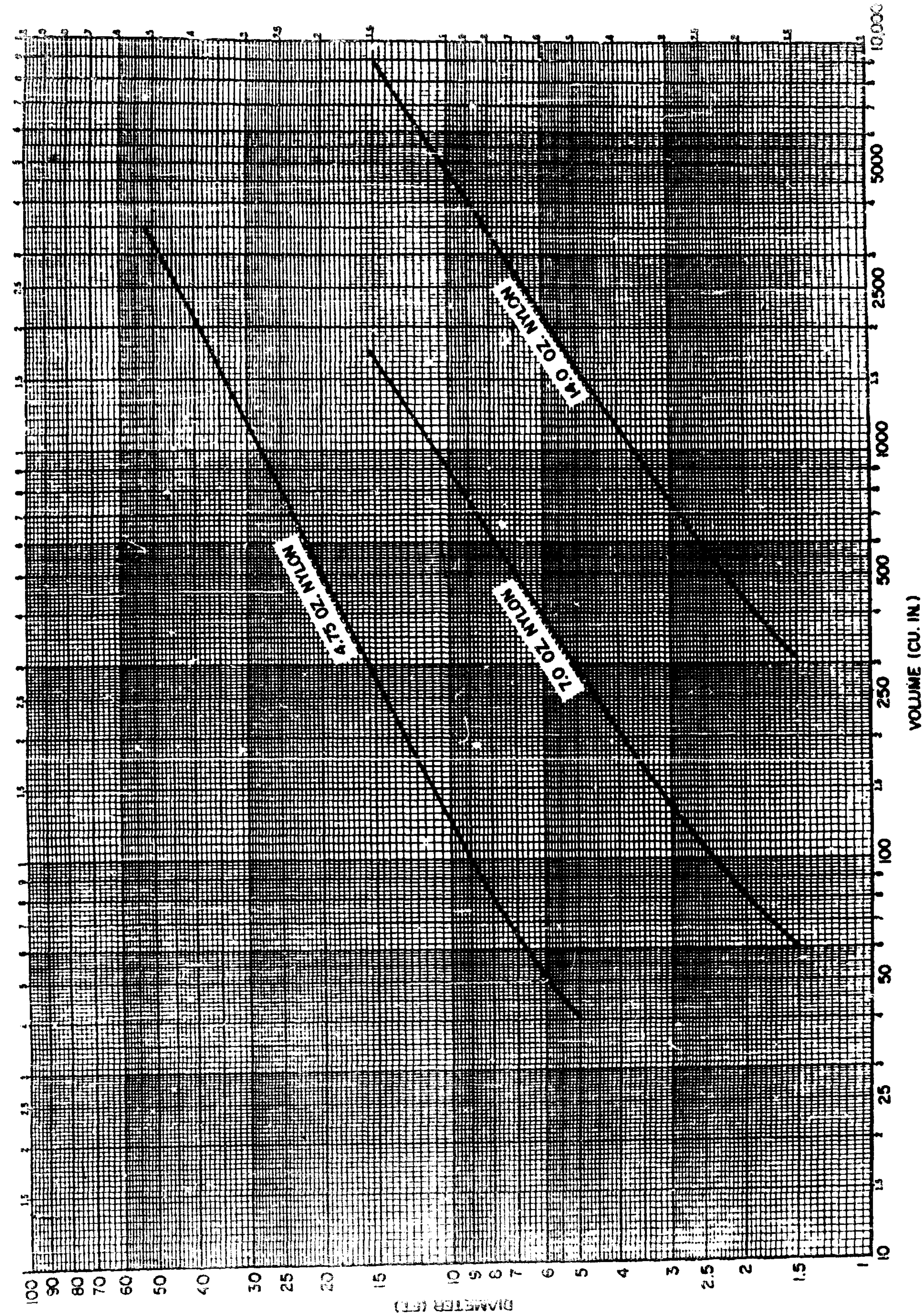
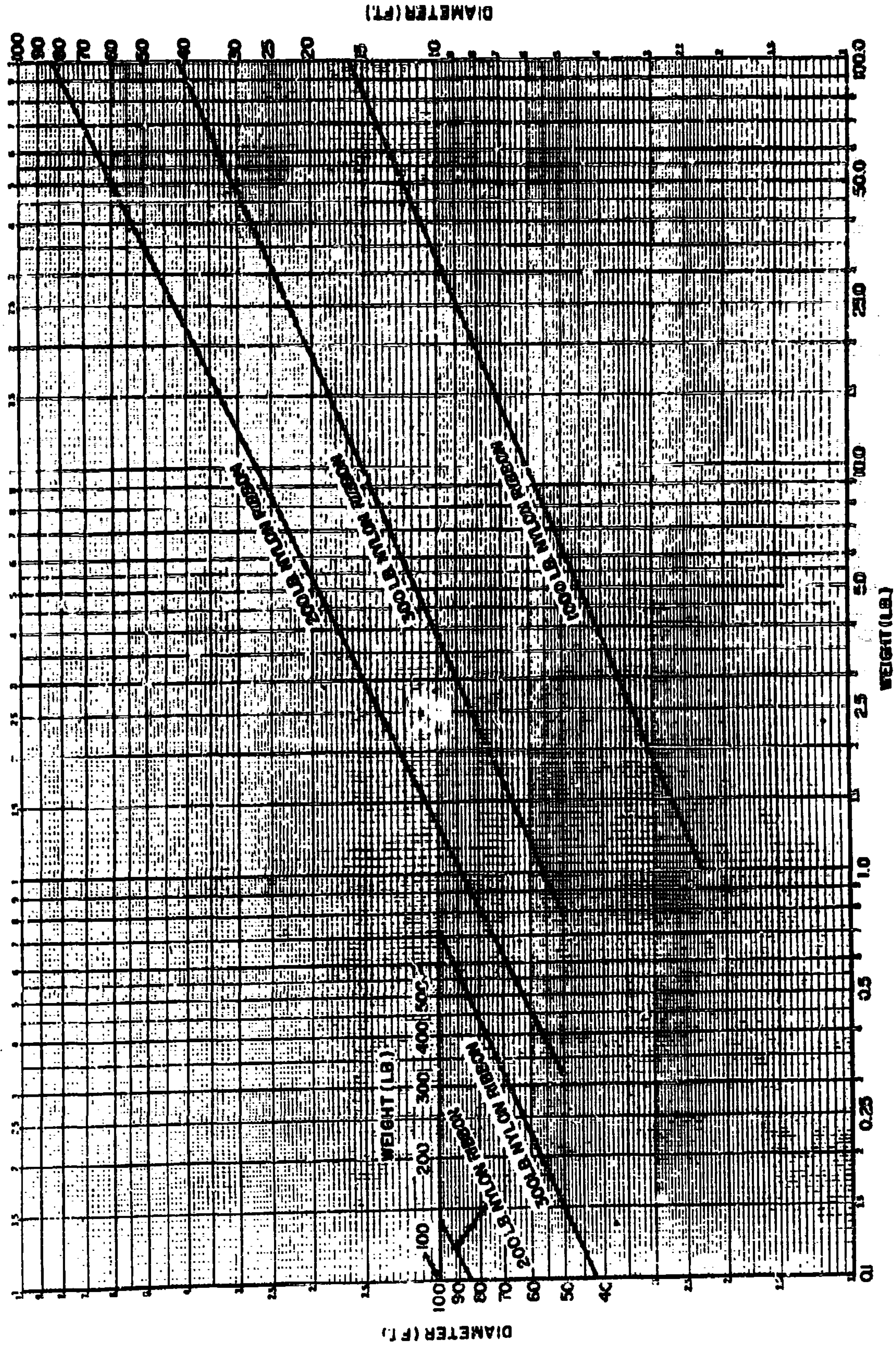


Figure 5-3-27. Weight and Volume, Ribless Guide Surface Type Parachute Canopy


DIAMETER (FT.)
WEIGHT (LB.)
200 LB NYLON RIBBON
300 LB NYLON RIBBON
1000 LB NYLON RIBBON
WEIGHT (LB.)
200 LB NYLON RIBBON
300 LB NYLON RIBBON
DIAMETER (F.T.)

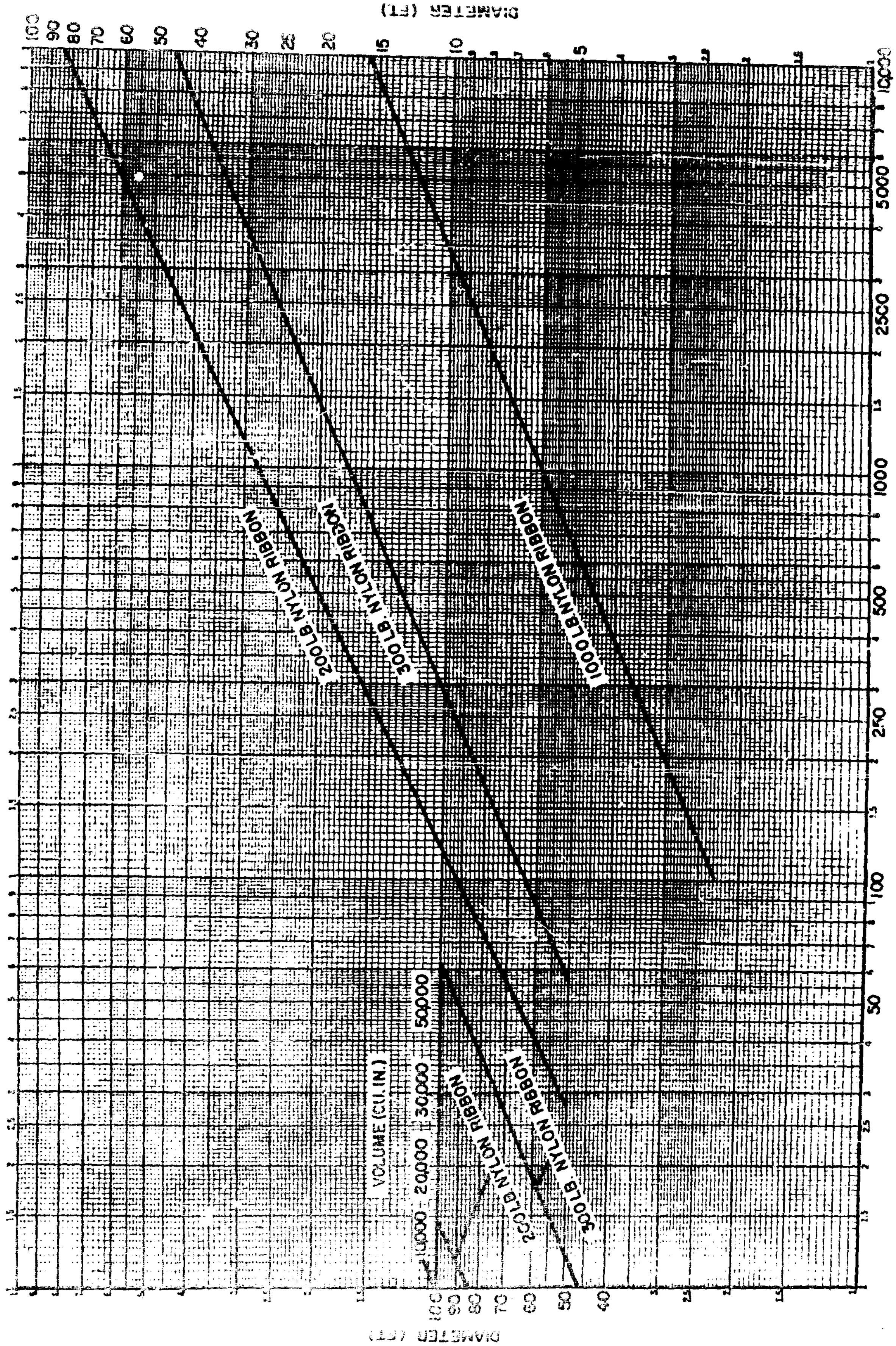
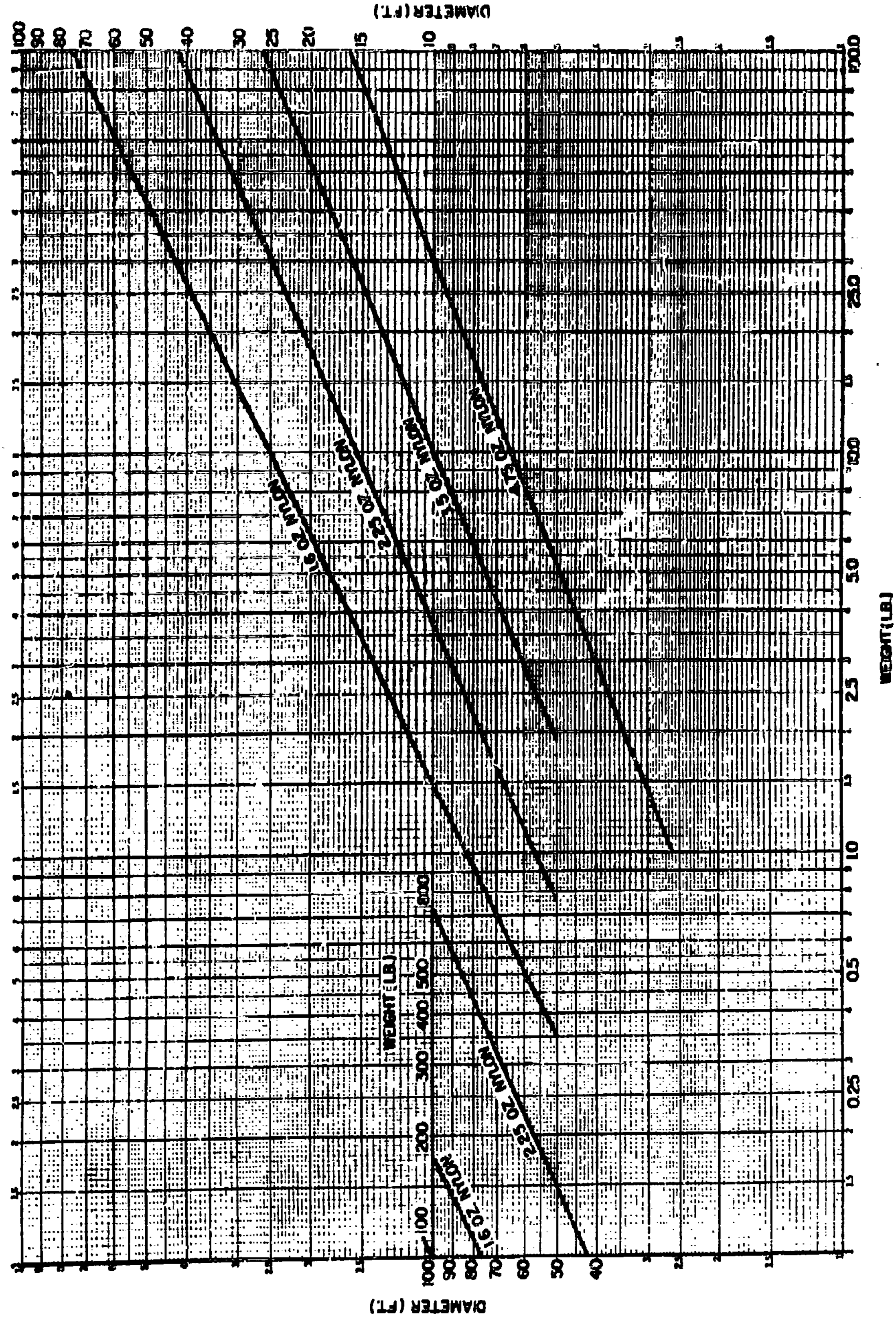


Figure 5-3-28. Weight and Volume, FIST Ribbon Type Parachute Canopy


DIAMETER (FT.)
WEIGHT (LB.)
1.6 OZ NYLON
2.25 OZ NYLON
3.5 OZ NYLON
DIAMETER (FT.)
WEIGHT (LB.)

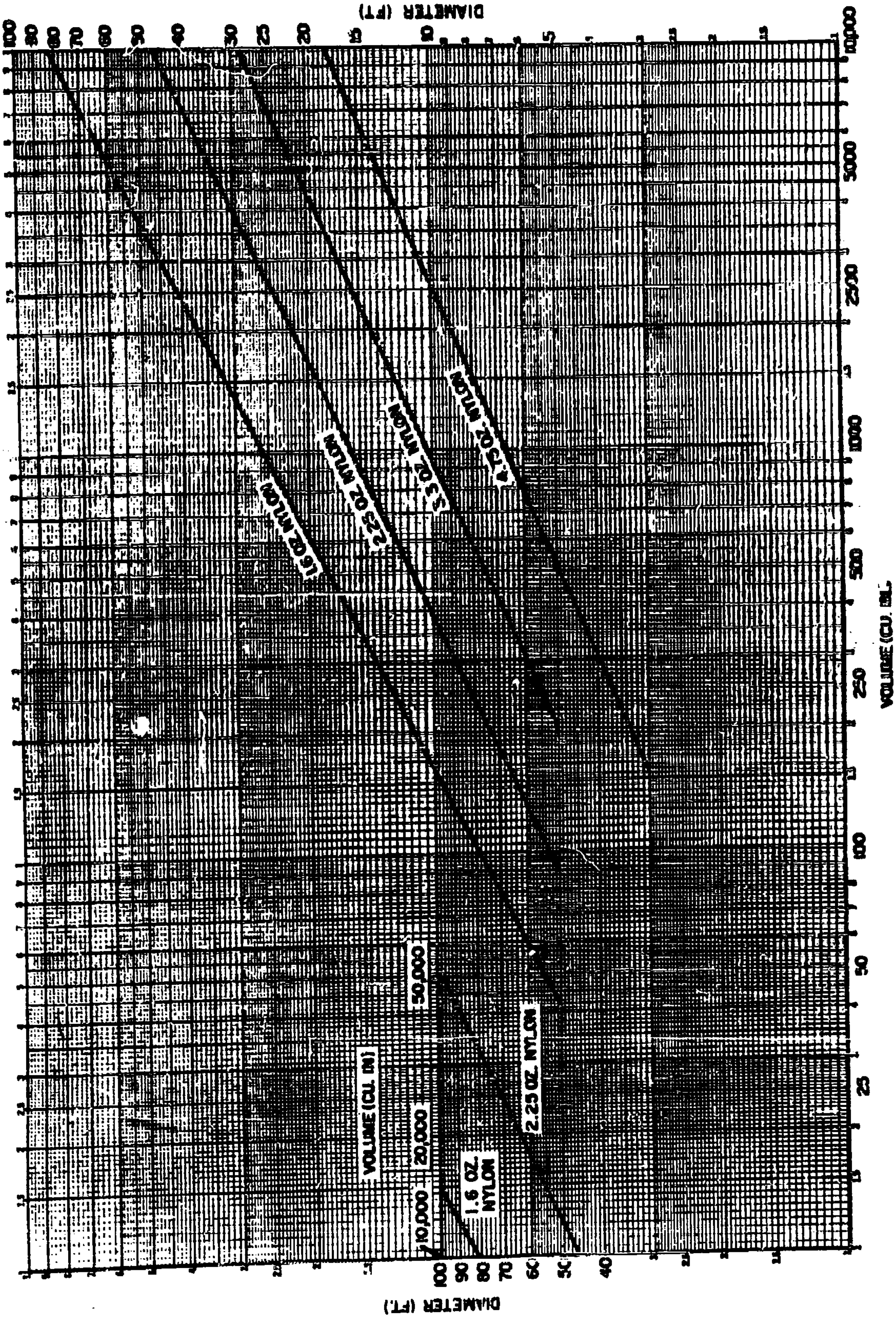


Figure 5-3-29. Weight and Volume, Ring slot Type Parachute Canopy

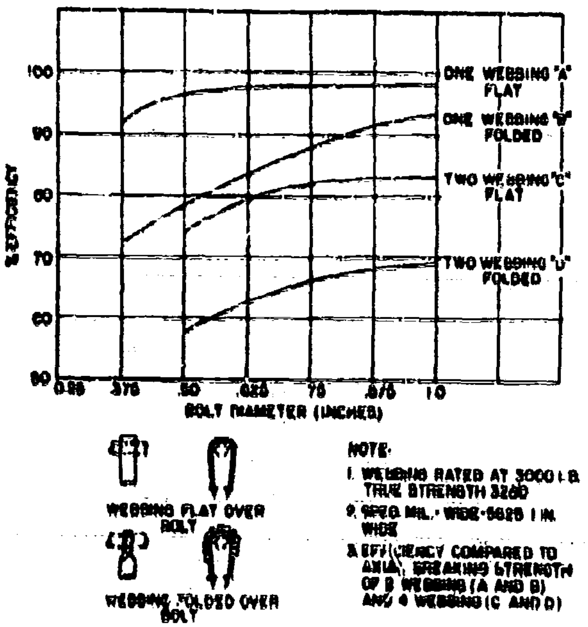


Figure 5-3-30. Efficiency of Various 3,000 lb Webbing Loops as Affected by the Bolt Diameter

100 percent, of the longest bag side adjacent to the bridle.

Line locking loops and permanent retaining loops are usually constructed of cotton materials, or of Nylon faced with cotton if high strength is required. Since locking loops are subject to high forces, it is usual to attach them to main longitudinal reinforcing webs. Locking loops are usually formed with the same webbing used to provide retaining loops or loops to which breakable tapes may be tied. Webs provided for tying breakable line retaining tapes are formed in much the same manner as permanent line loops.

Covers for line stowage areas may be formed very simply on the top or side of a deployment bag, as shown in Figure 5-3-35. Since suspension lines are not as sensitive to friction burns as cloth material, less attention need be paid to the smoothness of materials adjacent to lines. Nevertheless, no particularly

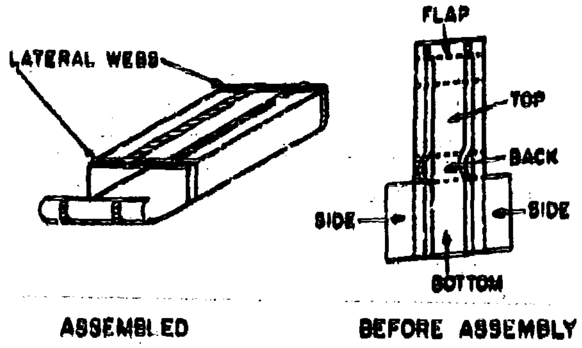


Figure 5-3-32. Trapezoidal Basic Container with Straight Reinforcement

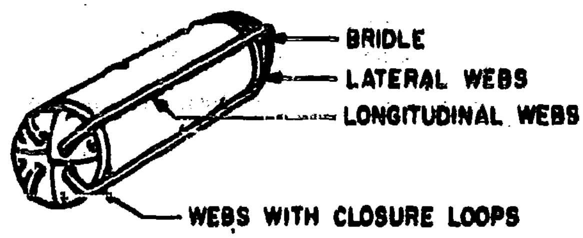


Figure 5-3-33. Cylindrical Bag Construction

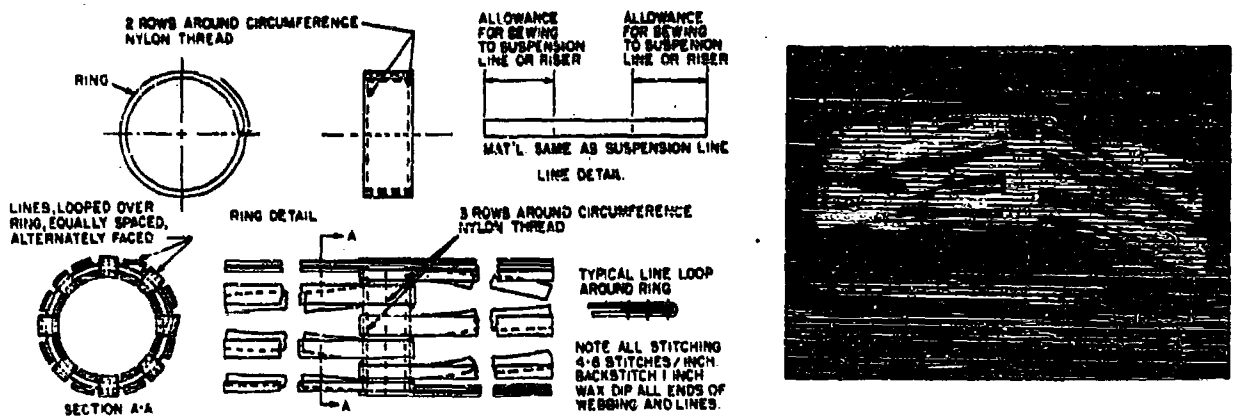


Figure 5-3-31. Typical Keeper Design for First Stage Missile Recovery Applications

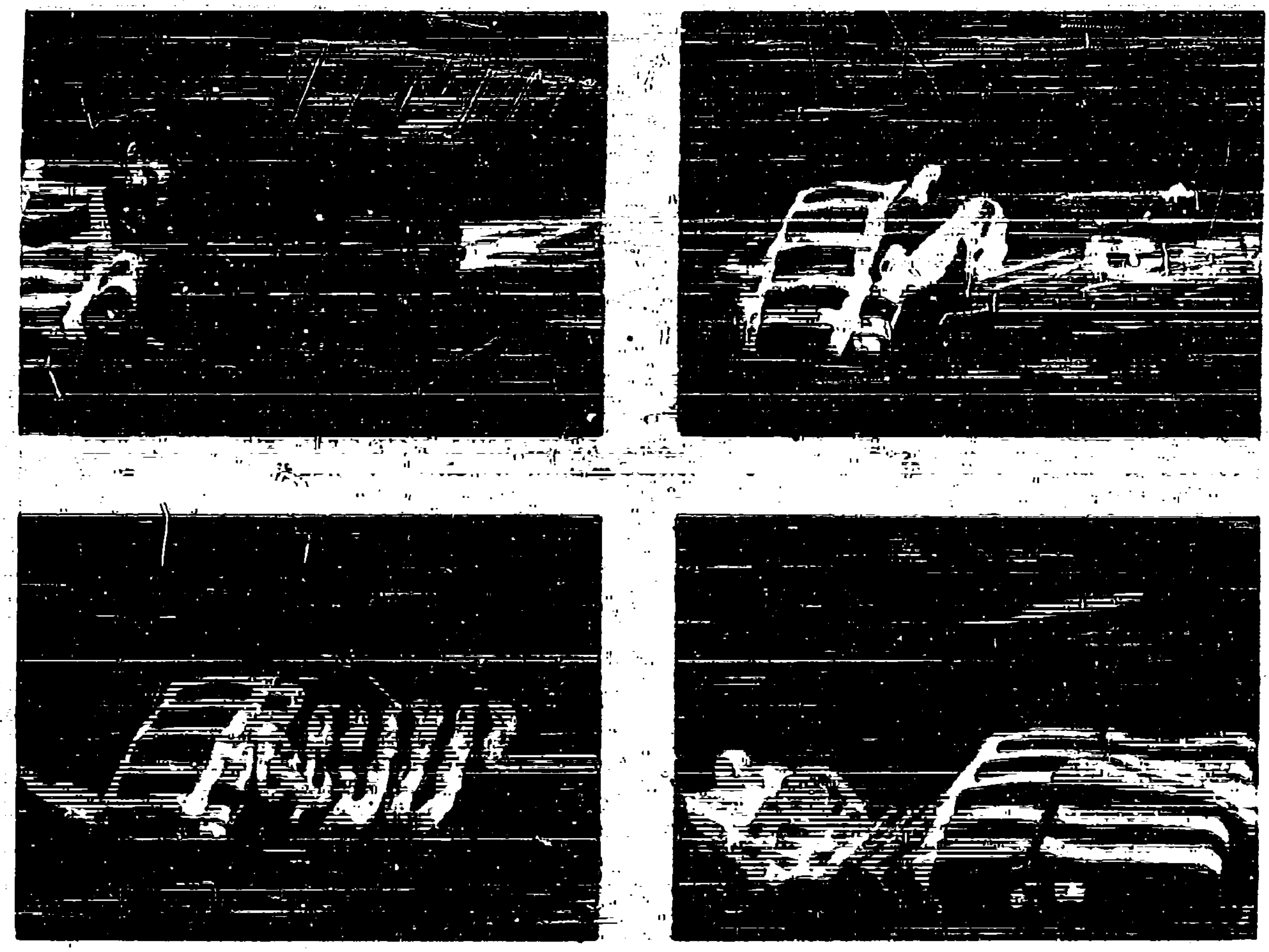


Figure 5-3-34. Heavy Parachute Deployment Bag for First Stage Missile Recovery Application

rough or hard weave fabrics should be allowed to bear on the lines. If necessary, line stowage areas may be lined with soft cotton fabric. If large risers and heavy hardware must be stowed on the bag, additional space may be provided by forming a large pocket on the line cover itself.

Line flaps, when placed at the mouth of a bag, are usually extensions of one bag side, and are constructed in much the same manner as a normal closure flap, as illustrated in Figure 5-3-36. Line retention loops may be added to stowage flaps in a manner discussed above; longitudinal reinforcements are extended down stowage flaps to provide strength for line retention.

3.7 PILOT CHUTES.

The use of proper pilot chutes is necessary for the purpose of activating positive and

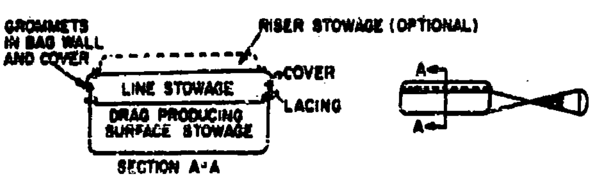


Figure 5-3-35. Cross-Section of Bag Showing Line Cover and Riser Cover

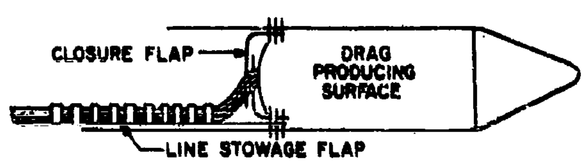


Figure 5-3-36. Construction of Line Stowage Flap

proper deployment for any parachute application, with exception of the static line, a deployment bag method in which a pilot chute is not employed.

A number of pilot chute types have been used experimentally, such as flat octagon, flat square, baseball, and hemispherical types. Almost all of those types were equipped with some sort of spring, or springs, to insure immediate opening. The standard pilot chute used for personnel, aerial delivery, aircraft deceleration, and other applications, was derived primarily from the flat octagon type pilot chute; however, vanes were added to obtain the following advantages:

a. The addition of vanes prevents the lines from entangling inside the parachute pack.
b. Should the pilot chute strike some object, the vanes would tend to slide past it rather than wrap about it or permit the object to pass between the lines.
c. The vanes cause the airflow to be directed into the pilot chute and act as a sail to aid in the deployment of the pilot chute from the pack.
d. The addition of vanes decreases the possibility of pilot chute canopy conversion.

A typical pilot chute, type MA-1, is shown in Figure 5-3-37. Basically, pilot chutes used for personnel, aerial delivery, and aircraft deceleration applications, have a hemispherical canopy and are constructed with a conical coil spring and vanes. In general, the canopy and the vanes of the pilot chute are constructed of the same material.

Of course, any of the conventional parachute canopy designs can be used as a pilot chute; however, a balance must be achieved between the required stability and drag. This is, to a certain extent, also true for weight and volume. For example, a Guide Surface type parachute canopy will have excellent stability but, due to its lower drag coefficient, it will require a larger sized canopy for a given force than would be required if the stability of a ring slot or flat circular type parachute canopy were acceptable. On the other hand, however, a slight increase in volume and weight must be tolerated. Drag coefficient and opening shock factor data for the most commonly used types of pilot chutes are listed in Table II.

TABLE II. PILOT CHUTE DATA

Type	Drag Coefficient	Opening Shock Factor
Vane	$c_{D_0} = 0.55$	2.5
Flat Circular	$c_{D_0} = 0.75$	2.5
Ring Slot	$c_{D_0} = 0.65$	1.5
FIST Ribbon	$c_{D_0} = 0.55$	1.5
Ribless Guide Surface	$c_D = 0.80$	2.0
Ribbed Guide Surface	$c_D = 0.95$	2.0

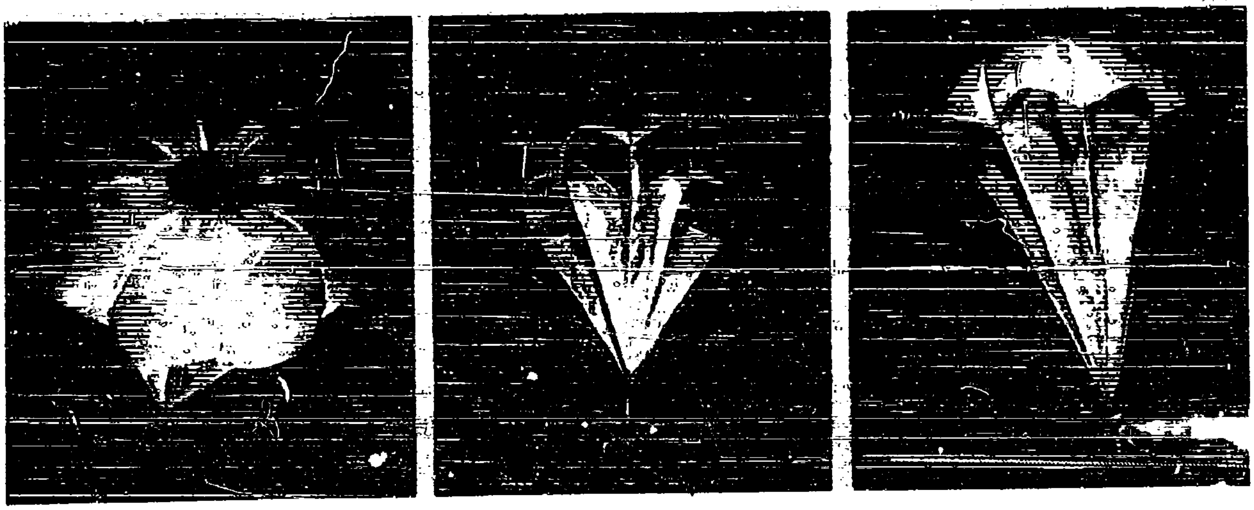


Figure 5-3-37. Pilot Chute, Type MA-1

The size of the pilot chute is of the utmost importance for positive and orderly deployment of the main canopy. No definite method has as yet been established to determine the required pilot chute size for any particular application; however, experience has shown that certain ratios of pilot chute drag area to main canopy drag area perform best. These data are given in Table III.

TABLE III. PILOT CHUTE TO MAIN CANOPY AREA RATIOS

Deployment Speed	$c_D S$ Ratios	Pilot Chute / Main Canopy
Up to 200 knots IAS	~ 0.03	~ 3%
200 to 300 knots IAS	~ 0.02	~ 2%
Over 300 knots IAS	~ 0.01	~ 1%

These data are only approximate and may have to be modified as determined by the particular parachute application. For high speed missile or capsule recovery application, for example, in which it is important to extract the main parachute canopies out of tight compartments and to insure orderly deployment sequences of the main canopies, pilot chutes of higher drag area ratios than those listed in Table III have been used. For the determination of correct pilot chute sizes, several other considerations, such as deployment speed ranges, wake effects, and breaking strength of ties, have to be taken into account. It should be remembered, however, that a certain energy is required to fulfill all the functions of a successful parachute deployment.

For high speed applications, pilot chutes of the Guide Surface type are commonly used. Because of their high speed application, these pilot chutes should be packed in separate deployment bags in order to separate snatch and opening forces of the pilot chute.

Fabrication methods for pilot chutes are identical to those employed for all other types of canopies.

The bridle between the pilot chute and the main canopy bag or the apex of the main canopy must be of sufficient length to prevent the suspended load from blanketing the pilot chute action. On the other hand, if the bridle is too long, the maximum snatch force or opening force exerted by the pilot chute will greatly increase; i.e. the opening shock factor will be greater than that given in Table II. In general, the bridle used should be of such length that the skirt of the inflated pilot chute will be 5 to 6 diameters of the suspended load behind the suspended load. The actual strength design of the bridle depends upon the maximum pilot chute force and the efficiency of the bridle connection. For strength calculations of bridles, see paragraph 3.4.

CHAPTER V

SECTION 4

PARACHUTE CONSTRUCTION DETAILS

4.1 GENERAL.

The methods by which the parachute may be assembled from its component parts are limited in number and variety, both by available equipment, principally sewing machines, and by the physical properties of applicable materials. While this is of major importance to the economics of parachute manufacturing, fabrication methods also have considerable influence on the strength, elasticity, and flexibility of the structure. These constitute design criteria relating mainly to details of assembly at seams, joints, and hems, the types of which depend on their location and function.

4.2 LAYOUT AND CUTTING.

The large number of pieces of material that must be handled and assembled to form a canopy makes it mandatory that layout markings and indexing points be held to a minimum. Since section edges can be cut accurately enough to serve as mating points as well as seam and hem bases, layout marks are not usually required on the fabric in the construction of large parachute canopies. Some dimensional variations will result from lack of uniformity in the lay of successive layers of fabric during the cutting operation. The flexibility of the weave pattern makes this a difficult factor to control, unless some form of temporary filler or sizing can be applied to the fabric.

Lines and tapes are measured and marked under sufficient tension to assure uniformity. A force of 20 pounds is commonly used for suspension lines, but tensions as low as 5 pounds are satisfactory for short lengths of heavy or unelastic materials, such as tapes and tubular webbings.

In constructions where the suspension lines pass over the drag producing surface, the skirt and vent edge intersection points are marked on the lines. Since the lines are stitched to the cloth surface only at the skirt and vent, the intervening fullness of fabric represents no problem. In all types of construction requiring the continuous attachment of tapes, webbings, and circumferential bands to the exterior surface of the cloth, uniform distribution of cloth fullness along the seam is difficult to achieve. It is frequently necessary to provide numerous intermediate indexing marks on both tape and cloth surfaces to guide the sewing, and tacking or basting may also be required. The main seams provide indexing marks for circumferential bands so that only the tape need be marked for each intersection. Radial dimension marks, however, are needed on the drag producing surface for reinforcing bands at intermediate locations between skirt and vent. The problem of distributing fullness along a seam arises, even though the measured lengths of cloth and tape are the same, because of the great difference in elasticity, but this difference diminishes with increasing weight of fabric.

4.3 SEWING AND STITCHING.

Stitching with thread by means of a variety of sewing machines, and sometimes by hand, is the traditional method for joining textiles. Strong, efficient joints result when the correct number, spacing, and pattern of stitchings are employed. The strongest type of stitch is the two-thread link stitch formed by most sewing machines when the proper tension is applied. Zigzag stitching, both single and double throw, is valuable in parachute work primarily because seams and joints so joined are capable of great elongation without creating excessive tensile stress in the thread itself.

Several difficulties of varying importance arise in the stitching together of parachute components. These difficulties must be watched closely. The tightness of the stitching resulting from the necessary thread tension has two effects which may be undesirable in certain types of seam, namely: because of gathering between each needle penetration, the finished length of the seam is shorter than the cut length of the material; and the binding together of the material creates friction, which reduces the flexibility and elasticity of the joint. In

machine sewing, differential feed can occur between the upper and lower pieces of material being joined, thus causing end mating points to pull out of register as the seam is sewn. Yarn filaments are broken by needle penetration, thereby weakening the basic fabric. The thread itself may be weakened or broken in thick joints and at seam intersections as a result of increased friction of penetration attending the superposition of successive rows of stitches. High speed sewing may weaken nylon materials by frictional overheating.

When differential feed or creep of materials can not be overcome to the extent required by the dimensional tolerances of the structure, basting may become necessary. Where the use of cement is permissible for basting, the quantity of cement applied to one point must be carefully metered so that the area of fabric affected is very small in diameter (generally, approximately 0.1 inch). All of the thicknesses of material at the seam or joint should be joined by one application on the center line or midpoint. The cement must set quickly and remain flexible with age. Successive cement spots on the same seam must be as widely spaced as practicable. Cementing, used primarily in the basting of ribbon type canopies for machine sewings, is considered undesirable because of possible deleterious effects on the ribbons, particularly at elevated temperatures. Typical examples of unsatisfactory seams are shown in Figure 5-4-1.

4.4 STRUCTURAL JOINTS.

The many types of hem and seam employed in the construction of parachute canopies have certain geometrical properties in common. The width of an integral reinforcing tape, and the number of rows and spacing of stitching, is determined by strength and other functional requirements. The width of hem or seam allowance is governed by the type form. The simplest types of hem and seam are generally used where the fraying of an exposed cut edge is not objectionable. Otherwise, an additional turn of fabric is required to place the cut edge inside. The rolled hem and French fell seam

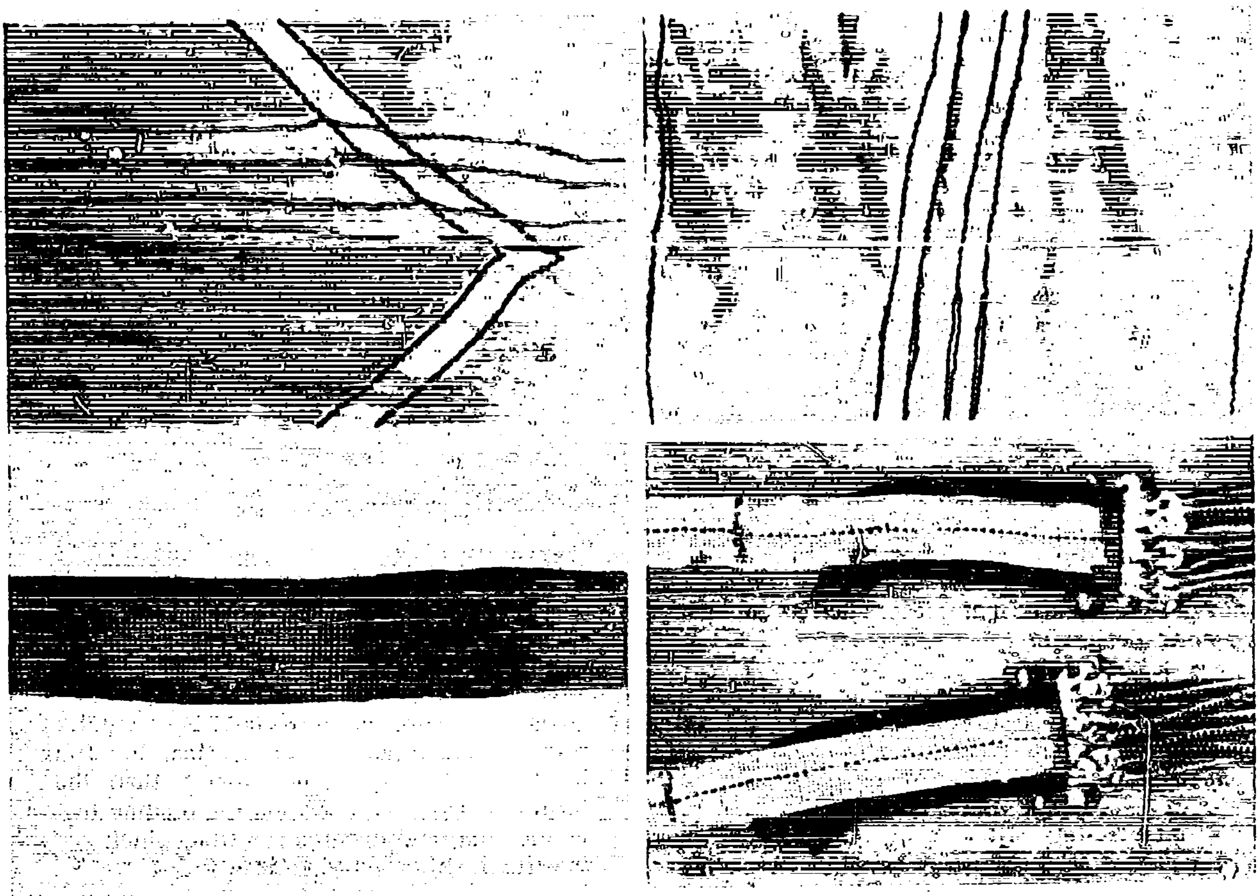


Figure 5-4-1. Typical Examples of Unsatisfactory Seams

are commonly employed for this reason, as well as for slightly greater strength. A bound hem is used occasionally, such as on the skirt and vent of the Ribless Guide Surface type parachute canopy (Figure 5-4-2). There, a narrow strip of fabric or webbing is applied to the cut edge and rolled under on each side. An integral reinforcing tape may also be bound into the hem at the same time by this means. A typical joint of roof panels of a Ribless Guide Surface type canopy is shown in Figure 5-4-3.

Geometrically porous canopies have many additional free edges that must be hemmed, except where selveges are strong enough alone, as on the ribbon type parachute canopies. Such factors materially affect the economy of fabrication.

In addition to the common practice of sewing the suspension lines to the drag producing surface at skirt and vent with double-throw zigzag stitches, there are such practices as:

a. Lines lapped over and stitched to the ends of main seam ribs or reinforcement tapes at the skirt. This arrangement is shown in Figure 5-4-4.
b. Lines tied to loops formed at the end of each main seam rib as shown in Figure 5-4-5.
c. Lines formed as continuous extensions of main seam ribs made of narrow webbing.

Joint reinforcements at the skirt, made of short lengths of tape or webbing, include the following arrangements:

a. The common "butterfly" tape shown in Figure 5-4-6.
b. A single lapped doubler.
c. Two-piece doublers, inside and out, and combinations of doublers, butterflies, and looped rib extensions.

The design objective, with respect to economy of fabrication, is to obtain optimum joint efficiency and serviceability with maximum simplicity of construction. The number of parts and operations must be the fewest possible consistent with functional requirements, and preference is given to operations that can be performed to advantage on high speed machines.

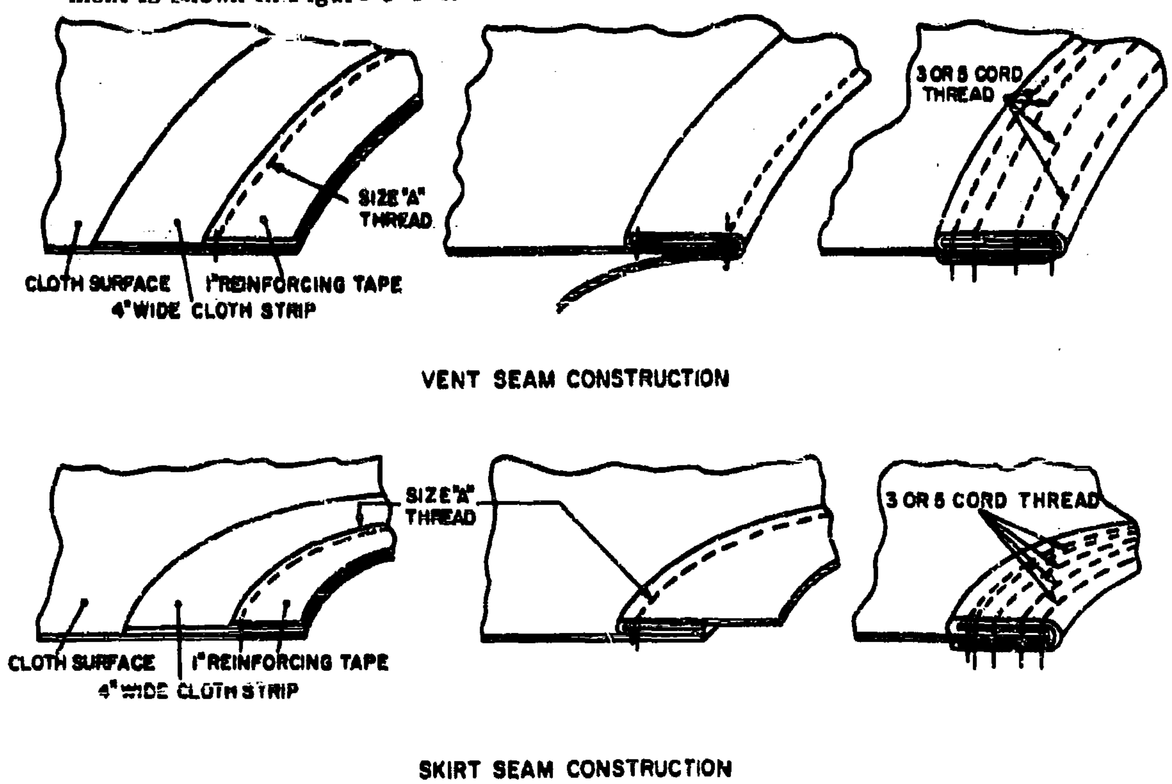


Figure 5-4-2. Skirt and Vent Construction, Ribless Guide Surface Type Parachute Canopy

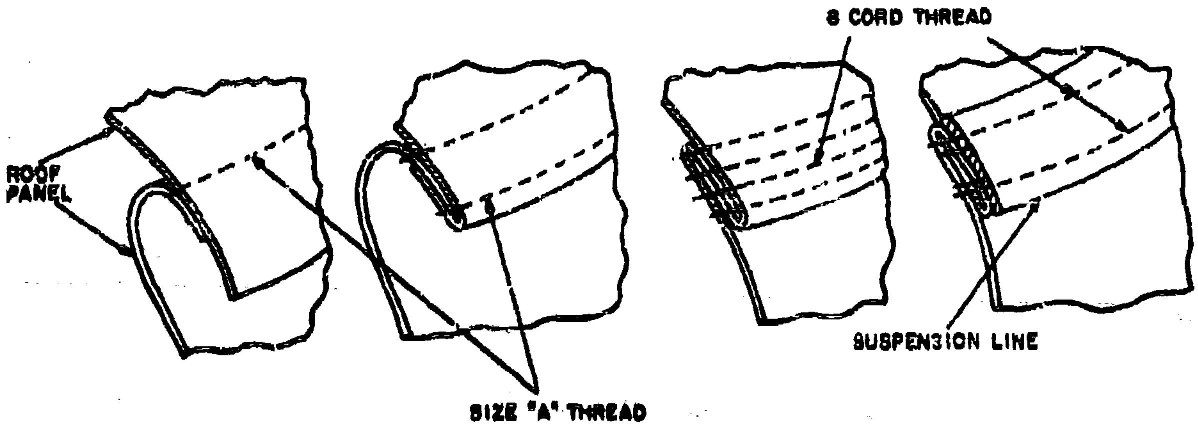


Figure 5-4-3. Typical Joint Construction of Roof Panels, Ribless Guide Surface Type

4.5 STRENGTH OF JOINTS AND SEAMS.

When joining fabric components into one complete structure, it is important to make the junction in such a manner that the strength of the joint is not below that of the components being joined. This ideal is not always realized. A relationship can be set up between the material and joint (joint efficiency factor), which is defined as

$$\eta = \frac{\text{Strength of Joint}}{\text{Strength of Material being joined}}$$

Failure can occur in one of two ways, or a combination of both. The first is the failure of the stitching thread, and the second, the failure of the materials being joined. Thread failures should normally occur in the efficiency range of 0-100%. The upper limit designates a fabric failure. The fabric is more likely to fail at the joint at a lower value than if the failure were in the unobstructed fabric. The probable cause for this is the weakening of the material by cutting, or damaging of the yarns as the needle passes through the fabric, or a local reduction of the elasticity because of friction between the layers caused by the tightness of the stitching. The strength of a sewn joint depends on the following covered in the paragraphs below.

4.5.1 TYPE OF STITCH. There are many different types of stitches, all described in the Federal Specifications for Stitches, Seams, and Stitching, DDD-S-751. The most frequently used are Type 301, which is formed by two

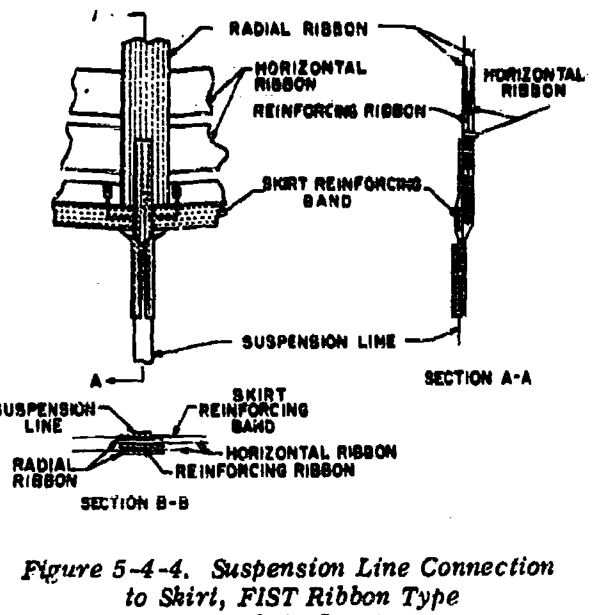


Figure 5-4-4. Suspension Line Connection to Skirt, FIST Ribbon Type Parachute Canopy

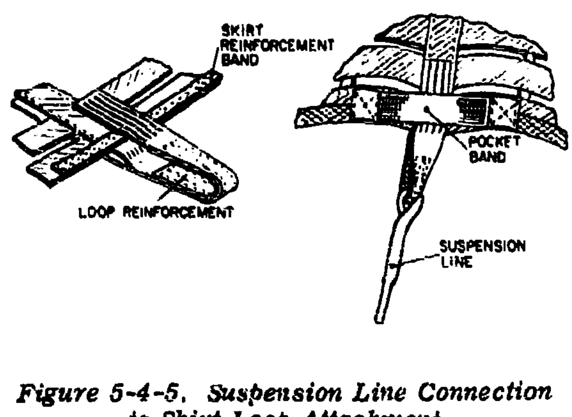


Figure 5-4-5. Suspension Line Connection to Skirt Loop Attachment

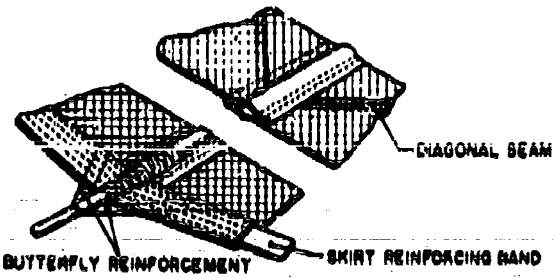


Figure 5-4-6. Joint Reinforcement, Butterfly Type

threads, and Type 304, which is similar but in a zigzag pattern (single throw). The elasticity of a seam, which depends on the type of stitch, should be the same as the elasticity of the adjoining material.

4.5.2 TYPE OF THREAD. Usually, the thread material is the same as the fabric being joined. Nylon and cotton threads are extensively used and are covered by Military Specifications. It is logical that, as the strength of the thread increases, the seam strength will increase, up to a point of 100% efficiency.

4.5.3 NUMBER OF STITCHES PER INCH AND STITCHING PATTERN. The stitching pattern depends on the materials being joined. The flat fabric seams consist of parallel rows of zigzag stitching. Formed fabrics, such as lines and webbings, employ patterns that are combinations of straight, cross, and zigzag stitching. The number of stitches per inch used depends on the strength required and the type of material, but is restricted by the working range of a given sewing machine. Both the number of stitches per inch and the pattern (number of rows) are varied to achieve the desired strength. It would be expected that an increase in either or both would increase the strength, up to some point where the nearness of the penetrations might possibly cause a decrease in strength. As the breaking strength of the fabric is surely not increased as the number of rows or stitches per inch is increased, it can be assumed that the thread failures, not the cloth strength, are contributing factors. However, if the strength of the cloth is reached, the addition of more stitches cannot make the seam any stronger. The dependence of seam efficiency on stitches per inch for various canopy cloth materials and rows of stitches is graphically illustrated in Figure 5-4-7.

4.5.4 SEAM CONSTRUCTION AND TYPE OF SEAM. In general, the type of the seam is dictated by the number and size of materials and reinforcements being joined. The common flat fabric seams are illustrated in Figure 5-4-8. The seam type has an effect on the resulting strength.

4.5.5 STRENGTH OF SUSPENSION LINE SEAMS. There are three different types of joints which occur in the suspension line system, the line-to-skirt type, the line-to-riser type, and the line-to-line type. In the suspension line-to-skirt joints, the suspension line joins the skirt periphery at a point where the main radial seam joins the skirt hem. The suspension line can be either a continuation of all or part of the members that make up the radial seam or it can be a separate member that is attached to the skirt. The former is always sewed to the canopy in the skirt band area, with reinforcements optional. The latter can be of two general types, a loop connection and an entirely sewed connection. In general, the looped joint is more efficient than the completely sewed joint, with η approximately 90%, compared to 80% for the entirely sewed type. The method of construction of the joint is partially suggested by the size of the members being joined. Other than this, a type is selected which has proved satisfactory in the past. Exceptions to this selection method are the parachute canopies constructed according to specifications, such as the FIST Ribbon and Ringslot types.

In the suspension line-to-riser joint, two basic types are used: a completely sewed joint, and a combination loop and sewed joint, sometimes with a metal link. The latter is the more common. The line is tied to the link and the free end attached to the line by various means.

The suspension line-to-line joint, in its most common form, is a stitched lap joint.

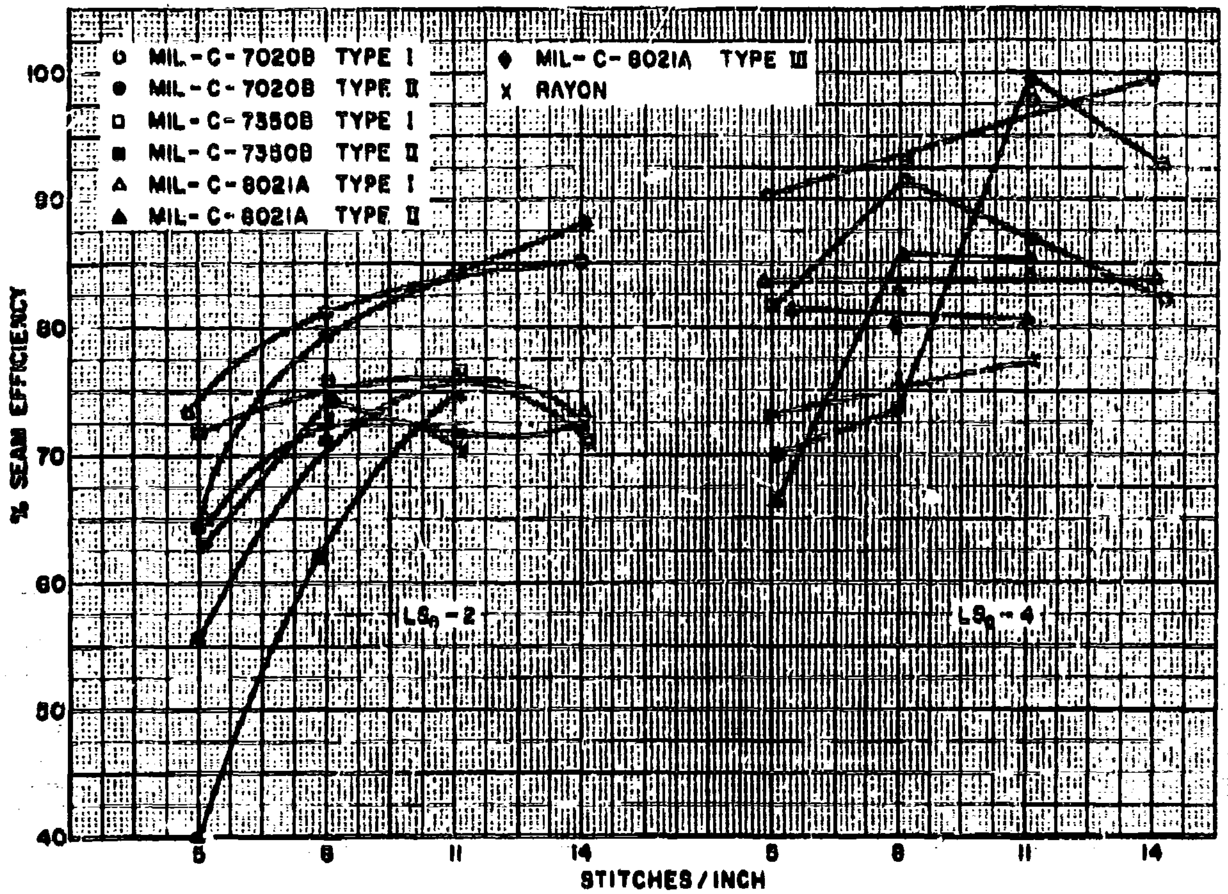


Figure 5-4-7. Dependence of Seam Efficiency on Stitches per Inch

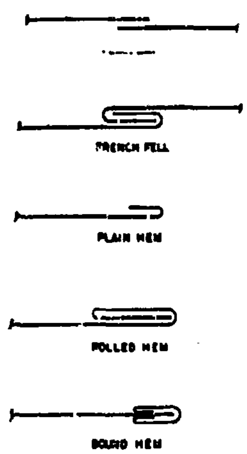


Figure 5-4-8. Typical Flat Fabric Seams

CHAPTER V

SECTION 5

PARACHUTE MATERIALS

5.1 GENERAL.

Since the parachute designer has little or no control over the actual design of textiles, he must have available the information necessary for the evaluation of the proper material for his specific application.

Selection of the most suitable material for parachute design is imperative. Not only is the strength of the parachute determined by the strength of the textile material, but also the actual parachute performance characteristics. Properties such as porosity and biaxial orientation of the load-carrying yarns must be taken into consideration.

The properties of the basic fiber, yarn, and final textile form, all differ to some degree. The material specifications given under paragraph 5.3 reflect the properties of the final form.

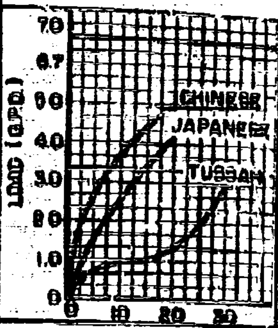
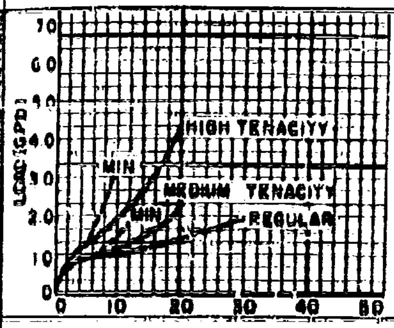
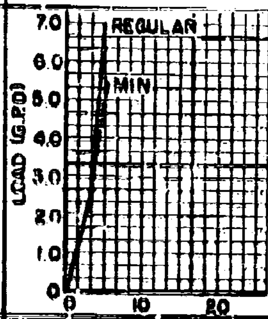
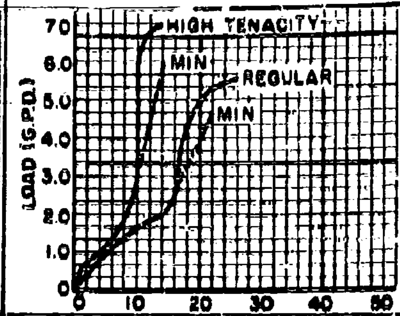
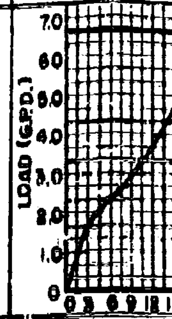
5.2 HEAT PROPERTIES OF MATERIALS.

Heat properties of the material must be considered, when the parachute stowage area cannot be properly insulated or ventilated. Generally, compartment temperatures should be limited to 250° F. for nylon, and 300° F. for dacron materials. At temperatures above 250° F. the rate of strength loss in nylon increases rapidly with increase in temperature. Also, the percentage loss in tenacity at 250° F. varies roughly as the logarithm of the time exposure. The melting point of nylon and dacron in air is approximately 482° F.

Detailed properties of natural and man-made fibers suitable for utilization in materials for parachute design are presented in Table I. Physical properties of these fibers are listed in Table II.

TABLE I. PROPERTIES OF NATURAL AND MA

PROPERTY	COTTON	SILK	VISCOSE RAYON	FORTISAN	NYLON
Effect of Heat	Highly resistant to dry heat; yellows at 248°F.; decomposes at 302°F.; burns freely in air	Begins to decompose at 270°F.; rapid disintegration above 300°F.; burns readily	Loses strength above 300°F.; decomposes at 350°F. to 400°F.; burns rapidly	Scorches in ironing at about 20°C. higher than cotton, otherwise about like cotton, viscose rayon	Yellows slightly 300°F. when exposed for 5 hr.; melts at 482°F.
Effect of Age	Little or none	Slight yellowing and loss of tensile strength	Slight	Little or none	Virtually none
Effect of Sunlight	Loss of strength; formation of oxycellulose; tendency to yellowing	Loss of tensile strength; affected more than cotton	Loses tensile strength after prolonged exposure; very little discoloration	Loses strength; tends to color	Loses strength on prolonged exposu no discoloration; bright yarn more resistant than semidull
Effect of Acids	Disintegrated by hot dilute acids or cold concentrated acids; unaffected by cold weak acids	Fairly resistant to weak acids; dissolved by strong acids except nitric which only yellows silk	Similar to cotton; hot dilute or cold concentrated disintegrate the fiber	Similar to cotton; hot dilute or cold concentrated disintegrate the fiber	Boiling in 5% HCl ultimately causes disintegration; dis solves with at leas partial decomposi tion in cold conc. solutions of sulfur or nitric acids
Effect of Alkalis	Swells (mercerization) in caustics, but no damage unless prolonged exposure in presence of air	Not sensitive to dilute alkalies unless hot; dissolves in strong alkalis above pH of 9.5	Strong solutions cause swelling and reduce the strength	Strong caustic shrinks; as in mercerizing	Substantially inert
Effect of Other Chemicals	Bleached by hypochlorites and peroxides, oxidized into oxycellulose by strong oxidizing agents; disintegrates in cuprammonium hydroxide	Above pH 11 and below pH 3 the stability decreases rapidly	Attacked by strong oxidizing agents; not damaged by hypochlorite or peroxide bleaches	Resistant to bleaches, phenols, and dyehouse reagents	Generally good resistance
Effect of Organic Solvents	Resistant	Resistant	Generally insoluble; soluble in cuprammonium	Unaffected	Generally insoluble; soluble in some phenolic compounds and in concentr. formic acid
Resistance to Moths	Wholly	Attacked, but partically resistant	Wholly	Wholly	Wholly
Resistance to Mildew	Poor, unless bleached or acetylated	Poor resistance	Attacked	Same as for cotton	Wholly

N	SILK	RAYON			NYLON		ORLON
		VISCOSE		FORTISAN			
							
on	% Elongation	% Elongation		% Elongation	% Elongation		% Elongation
		Filament & Staple		Filament	Filament		Filament
		Regular	High tenacity		Regular	High tenacity	
land	2.80 to 6.00	1.5 to 2.4	3.0 to 4.6	7.0	4.6 to 5.8	6.1 to 7.4	4.2 to 4.8
9	9.92 to 17.72	5.31 to 8.50	10.62 to 16.30	24.80	16.30 to 20.55	21.61 to 26.22	14.88 to 17.01
land	2.10 to 4.50	0.7 to 1.2	1.9 to 3.0	6.0	4.0 to 5.1	5.3 to 6.4	4.0 to 4.6
7	7.74 to 15.94	2.48 to 4.26	6.73 to 10.62	21.26	14.17 to 18.07	18.78 to 22.68	14.17 to 16.30
		1.0 to 1.5	1.8 to 2.1		3.9 to 5.0	5.1 to 6.2	3.1 to 3.5
		3.54 to 5.31	6.38 to 7.44		13.82 to 17.72	18.07 to 21.97	10.98 to 12.40
	13 to 20	20 to 35	14 to 20	6.0	30 to 37	21 to 28	15 to 17
		30 to 74 @ 4%	70 to 100 @ 2%	60% @ 40% T. S. 100% @ 20% T. S.	100 @ 2% 100 @ 8%	100 @ 4%	97% @ 2% 75% @ 8%
	96 @ 1% 59 @ 5%	11.1	25.5	117	18	32	28
	15	.19	.22	.21	1.08	.77	.41
	.30	29,000 to 46,000	58,000 to 88,500	136,000	57,000 to 85,000	89,000 to 108,000	62,000 to 71,0
	1.25	1.50 to 1.52		1.5	1.14	1.14	1.14 to 1.17
		.7 to 1.4	1.7 to 2.0		3.9 to 5.1	5.3 to 6.3	3.0 to 3.3
		2.48 to 4.96	6.02 to 7.09		13.82 to 18.07	18.78 to 22.32	10.63 to 11.69

5.3 TABULATION OF PARACHUTE MATERIALS.

Nomenclature	Specification No.	Type	Breaking Strength (lb.)	Size: Width (in.)	Size: Thickness (in.)	Weight (oz. per yd.)	Notes
Webbing, textile, woven, nylon	MIL-W-4088B (USAF)	I	500	9/16±1/32	0.03 to 0.04	0.28	Color: Green, Color No. 3412, unless otherwise specified.
		II	600	1 ±1/32	0.03 to 0.04	0.42	Finish: Condition R — Resin treated
		III	800	1 1/4 ±1/32	0.03 to 0.04	0.52	Condition U — Untreated
		IV	1,800	3 ±1/32	0.03 to 0.04	1.20	
		V	3,000	5 ±1/8	0.03 to 0.04	2.10	
		VI	1,800	1-23/32±1/16	0.05 to 0.06	1.20	Code: 2 red threads in center.
		VII	5,000	1-23/32±1/16	0.08 to 0.11	2.50	Code: 2 yellow threads each edge.
		VIII	3,600	1-23/32±1/16	0.065 to 0.085	1.70	Code: 2 black threads in center.
		IX	8,200	3 ±1/8	0.10 to 0.125	4.20	
		X	8,700	1-23/32±1/16	0.125 to 0.145	3.70	
		XI	2,400	1 ±1/32	0.07 to 0.09	1.15	
		XII	1,200	1-23/32±1/16	0.03 to 0.04	0.85	Code: 1 red thread each edge.
		XIII	6,000	1-23/32±1/16	0.10 to 0.12	2.90	Code: 1 black thread each edge.
		XIV	1,200	1/2 ±1/32	0.08 to 0.10	0.80	
		XV	1,500	2 ±1/16	0.04 to 0.05	1.25	
		XVI	4,500	1-23/32±1/16	0.07 to 0.095	2.20	
		XVII	2,400	1 ±1/32	0.055 to 0.07	1.15	
		XVIII	6,000	1 ±1/16	0.11 to 0.16	2.35	
		XIX	10,000	1 3/4 ±1/16	0.11 to 0.13	3.40	Code: 2 green threads in center.

Nomenclature	Specification No.	Type	Breaking Strength (lb.)	Size: Width (in.)	Size: Thickness (in.)	Weight (oz. per yd.)	Notes
Webbing, textile, nylon, heavy-duty	MIL-W-5787B	I	20,000	1 3/4	0.375	9.0	Color: Olive drab unless otherwise specified.
		II	40,000	3 1/8	0.480	18.0	
Webbing, textile, woven, cotton warp	MIL-W-005665C	I	350	9/16±1/16	0.04 to 0.05	0.40	Color: Natural unless otherwise specified.
		II	575	1 ±1/16	0.04 to 0.05	0.75	Class: 1A — Undyed and not fungus-proofed. 1B — Undyed and fungus-proofed. 2A — Dyed and not fungus-proofed. 2B — Dyed and fungus-proofed. S — Resin-dyed and fungus-proofed during dyeing
		III	750	1 1/4 ±1/16	0.04 to 0.05	0.90	
		IV	1,900	3 ±1/8	0.05 to 0.10	2.50	
		V	3,100	5 ±1/8	0.05 to 0.10	4.30	
		VI	1,800	1 3/4 ±1/16	0.07 to 0.09	2.10	
		VII	2,600	1 3/4 ±1/16	0.14 to 0.17	3.0	Code: 2 black threads along edge.
		VIII	2,900	1 3/4 ±1/16	0.075 to 0.09	3.0	Code: 2 black threads in center.
		IX	4,500	3 ±1/8	0.09 to 0.115	4.65	
		X	5,000	1 3/4 ±1/16	0.125 to 0.14	3.50	Nylon filling yarns used in Types VIII, X, XV, and XVI.
		XI	1,000	1 ±1/16	0.09 to 0.11	1.35	
		XII	1,000	1 3/4 ±1/16	0.04 to 0.05	1.25	Fungus-proofed webbing to retain 90% of strength after exposure to biological tests.
		XIII	3,400	1 3/4 ±1/16	0.10 to 0.13	3.40	
		XIV	5,200	3 ±1/8	0.09 to 0.12	4.95	
		XV	4,500	1 3/4 ±1/16	0.125 to 0.14	3.50	Code: 2 red threads along edge.
		XVI	2,700	1 3/4 ±1/16	0.095 to 0.115	0.60	Code: 2 yellow threads in center.

Nomenclature	Specification No.	Class	Type	Width (in.)	Breaking Strength Full Width	Min. Weight (yds. per lb.)	Min. Elongation (%)	Porosity at 1/2-in. H_2O	Notes
Ribbon, nylon, parachute (cont)	MIL-R-5608B (cont)	B	I	1/4±1/64	22	970	18	—	Class / Description / Yarn Denier: Warp / Fill
		B	II	3/8±1/64	33	650	18	—	A Extra light wt. 20 / 40
		B	III	5/8±1/32	70	360	18	—	B Light wt. 30 / 40
		B	IV	1 1/4±1/16	120	210	18	—	C Medium wt. 40 / 40
		B	V	2 ±1/16	200	120	18	150±30	D Heavy wt. 210 / 210
		B	VI	5 ±3/16	500	50	18	150±30	E Extra heavy wt. 210 / 210
		C	I	1/4±1/64	39	770	22	—	
		C	II	3/8±1/64	58	520	22	—	
		C	III	5/8±1/32	90	335	22	—	
		C	IV	1 1/4±1/16	185	160	22	—	
		C	V	2 ±1/16	300	100	22	150±30	
		D	I	1 1/4±1/16	280	80	18	—	
		D	II	2 ±1/16	460	45	18	—	
		E	I	1 1/4±1/16	650	50	18	—	
		E	II	2 ±1/16	1,000	30	18	—	

Nomenclature	Specification No.	Type	Class or Weave	Weight (oz. per yd.^{2})	Strength (lb. per in.) Tensile Warp	Tensile Fill	Tear Warp	Tear Fill	Min. Elongation (%)	Porosity at 1/2-in. H_2O	Notes
Cloth, nylon, parachute	MIL-C-7020B (ASG)	I	Rip-stop	1.1	40	40	3.5	3.5	22	80 to 120	Color: Natural unless otherwise specified.
		II	Twill	1.6	50	50	4	4	14	100 to 160	
		III	Rip-stop	1.6	50	50	4	4	14	100 to 160	
Cloth, nylon, cargo parachute	MIL-C-7350B (ASG)	I	Plain	2.25	90	90	15	12	25	100 to 150	Color: Natural unless otherwise specified.
		II	Plain	3.5	135	125	30	30	25	150 to 200	
Cloth, nylon, drag parachute	MIL-C-8021A	I	--	4.75	200	200	15	15	30	50 to 80	Color: Natural unless otherwise specified.
		II	--	7.0	300	300	20	20	30	50 to 80	Bolt width ÷ 36.5 ± 0.5 in.
		III	--	14.0	600	600	75	75	30	15 to 55	
Cloth, rayon, parachute	MIL-C-8006 (USAF)	I	--	4.25	85	80	10	10	15	150 ± 30	High tenacity.
		II	--	4.5	80	80	10	10	15	150 ± 30	Semi-high tenacity.
		III	1	8.0	145	135	30	30	18	180 ± 40	Regular tenacity.
		III	2	4.5	75	70	10	10	15	150 ± 30	Color: As specified by procuring agency.
		III	3	1.5	25	25	2	2	18	200 ± 40	

Nomenclature	Specification No.	Type	Breaking Strength (lb.)	Size Width (in.)	Size Thickness (in.)	Weight (oz. per yd.)	Min. Elongation (%)	Notes
Tape, nylon reinforcing	MIL-T-5038	II	900	1	0.025 to 0.035	0.90	18	Color: Natural unless otherwise specified.
		II	1,700	2	0.025 to 0.035	0.80	18	
		III	200	3/8	0.015 to 0.025	0.12	18	

Nomenclature	Specification No.	Type	Breaking Strength (lb.)	Size: Width (in.)	Size: Thickness (in.)	Weight (oz. per yd.)	Min. Elongation (%)	Notes
Tape, nylon reinforcing (cont)	MIL-T-5038 (cont)	III	250	1/2	0.015 to 0.025	0.15	18	Type II — Herringbone twill. III — Plain weave. IV — Plain weave. V — Herringbone twill. VI — Herringbone twill.
		III	400	3/4	0.015 to 0.025	0.20	18	
		III	525	1	0.015 to 0.025	0.30	18	
		IV	1,000	1	0.035 to 0.045	0.50	18	
		IV	1,100	1-1/8	0.035 to 0.045	0.60	18	
		IV	1,500	1-1/4	0.035 to 0.045	0.75	18	
		V	500	9/16	0.02 to 0.03	0.20	18	
		VI	425	3/4	0.02 to 0.03	0.20	18	
Tape, textile (parachute construction)	MIL-T-5663A	--	300	1 ± 1/16	0.01 to 0.03	110 to 130 yds. per lb.	14	Color: Natural unless otherwise specified. Material: Nylon with cotton filling. Use: Reinforcing bands.
Tape, textile, woven, nylon	MIL-T-8363 (USAF)	I	350	5/16±1/32	0.03 to 0.04	0.08		Color: AF sage green unless otherwise specified. Use: Lacing, flight clothing, etc.
		II	290	7/16±1/32	0.02 to 0.03	0.09		
Tape, cotton, reinforcing	MIL-T-5661A	I	80	1/4		0.11		Color: Natural unless otherwise specified (see Type III — 3/4-in. wide). Weave Pattern: Type I — Plain. II — Double herringbone III — Twill. IV — Special (see spec.). V — Plain.
		I	120	3/8		0.15		
		I	150	1/2		0.22		
		I	170	5/8		0.28		
		I	200	3/4		0.33		
		I	250	1		0.47		
		II	110	1/2		0.15		
		II	165	3/4		0.22		
		II	220	1		0.26		
		II	275	1-1/4		0.36		

Nomenclature	Specification No.	Type	Breaking Strength (lb.)	Size: Width (in.)	Size: Thickness (in.)	Weight (oz. per yd.)	Min. Elongation (%)	Notes
Tape, cotton, reinforcing (cont)	MIL-T-5661A (cont)	II	330	1-1/2		0.43		Color: A/C gray.
		II	375	1-3/4		0.50		
		II	425	2		0.57		
		III	45	1/2		0.10		
		III	55	5/8		0.12		
		III	75	3/4		0.14		
		IV	115	3/4		0.30		
		IV	150	1		0.40		
		IV	165	1-1/8		0.45		
		IV	590	1-1/4		1.20		
		IV	215	1-1/2		0.60		
		V	350	1		0.60		
		V	650	2		1.30		

Nomenclature	Specification No.	Style	Size	Min. Break Strength: Type I	Min. Break Strength: Type II	Weight (yd. per lb.): Type I	Weight (yd. per lb.): Type II	Notes
Thread, nylon	MIL-T-7807		0000	0.85	0.85	42,200	40,000	Color: Natural unless otherwise specified.
			000	1.30	1.30	29,500	26,000	Type I — Machine twist.
			00	1.85	1.85	25,800	23,000	II — Twisted bonded multicord.
			A	2.75	2.75	16,900	15,000	III — Bonded monocord.
			B	5.50	5.50	8,200	7,375	IV — Hand sewing twist.
			E	8.50	8.50	5,600	5,000	V — Buttonhole twist.
			F	11.00	11.00	3,750	3,350	VI — Braided shoe.
			FF	16.00	16.00	2,725	2,450	

Nomenclature	Specification No.	Style	Size	Min. Break Strength		Weight (yd. per lb.)		Notes
				Type I	Type II	Type I	Type II	
Thread, nylon (cont)	MIL-T-7807 (cont)		3-cord	24.00	24.00	1,800	1,600	Classes for Type I and II Thread Only
			4-cord	32.00	32.00	1,300	1,200	1 - Low stretch -- max. elongation 22%
			5-cord	40.00	40.00	1,000	950	2 - Normal stretch -- max. elongation 40%
			6-cord	50.00	50.00	850	775	For Parachutes and Flight Safety Equipment
			7-cord	60.00	60.00	725	650	Use Type I -- Class 1 } Only
			8-cord	68.00	68.00	625	575	or Type II -- Class 1 }
			9-cord	80.00	80.00	550	500	
			10-cord	90.00	90.00	450	450	
Thread, cotton, high-tenacity	MIL-T-5660A (ASG)	"A"	3	115	16	1,850	1,775	Color - To be specified by the procuring agency.
		"A"	4	20	21	1,250	1,200	
		"A"	5	30	31	900	880	Style "A" - Lockstitch twist thread.
		"A"	6	36	37	750	720	"B" - Stitching thread.
		"A"	7	40	41	650	625	Type I - Soft finish.
		"A"	8	44	45	550	525	II - Polish finish.
		"A"	9	51	51	530	500	
		"A"	10	53	62	500	480	Fungus-proof per Spec. MIL-T-5030.
		"B"	25	--	12	--	2,400	
		"B"	30	--	10	--	2,800	
		"B"	35	--	8-1/2	--	3,300	
		"B"	40	--	7-1/2	--	3,800	
		"B"	50	--	6	--	4,750	

Nomenclature	Specification No.	Type	Breaking Strength	Approximate Size Width	Approximate Size Thickness	Weight (yd. per lb.)	Elongation (%)	Notes
Cord, rayon, without core, braided	MIL-C-4232 (USAF)	I	400			42	14	Color: Natural unless otherwise specified.
		II	1,000			20	12	
		III	1,500			13	—	
Cord, nylon	MIL-C-5040A (ASG)	I	100			350	—	Color: Natural unless otherwise specified.
		II	375			105	—	Type II to have 1 black thread in sleeve.
		III	550			75	—	
Cord, nylon, coreless	MIL-C-7215 (USAF)	I	400			110	20	Color: Natural unless otherwise specified.
		II	550			85	20	
		III	750			50	20	Type III similar to cord, nylon, 750-pound, Spec. MIL-C-7981 (Aer)
		IV	1,000			40	20	
		V	1,500			25	20	
		VI	2,000			20	—	
		VII	2,400			15	--	
		VIII	3,000			12	--	
		IX	4,000			9	—	
		X	5,000			7.5	—	

Nomenclature	Specification No.	Type	Class or Weave	Weight (oz. per $yd.^2$)	Strength (lb. per in.) Tensile Warp	Tensile Fill	Tear Warp	Tear Fill	Min. Elongation (%)	Porosity at 1/2-in. H_2O	Notes
Pack cloth, parachute, nylon	MIL-C-7219A (ASG)	I	Plain weave	9.50	400	300	35	45	None spec.	5.0	Color: As specified by procuring agency
		III	Plain weave	7.25	325	275	20	20	None spec.	8.0	Color: As specified by procuring agency

Nomenclature	Specification No.	Type	Class or Weave	Weight (oz. per yd.^{2})	Strength (lb. per in.) Tensile Warp	Tensile Fill	Tear Warp	Tear Fill	Min. Elongation %	Porosity at 1/2-in. H_2O	Notes
Pack cloth, parachute, cotton	CCC-D-771B	II	Plain weave	No. 8 18.0	275	190					
			Plain weave	No. 10 14.73	240	145					
			Plain weave	No. 12	185	110					
		IV	Plain weave	7.9	120	110					
			Plain weave	9.65	150	95					
			Plain weave	12.00	200	115					
			Plain weave	14.50	225	160					

CHAPTER 5

SECTION 6

SAMPLE PARACHUTE CALCULATION

6.1 GENERAL.

This sample calculation has been included to serve as a guide for steps to be taken to design a parachute canopy for a particular application. For the purpose of this sample calculation, FIST Ribbon type parachute canopies are considered.

6.2 DECELERATION BY PARACHUTE.

As pointed out in previous chapters, deceleration parachutes are used for deceleration of high speed aircraft in case of emergency, during aircraft approach and landing, and in the first stages of missile and drone recoveries.

In level flight, the mechanism of deceleration is as follows: The decelerating force equals the drag developed by the parachute canopy. Hence

$$D = c_{D_o} S_o \frac{\rho}{2} v^2 = \frac{W}{g} \frac{\overline{dv}}{dt} = \frac{\overline{dv/dt}}{g} W$$

wherein $c_{D_o} S_o \frac{\rho}{2} v^2$ represents the drag term

and W/g is the mass of the aircraft to be decelerated. It should be noted that the deceleration dv/dt in ft. per sec.^{2} is a negative quantity. The absolute value is considered, however, in the above equation. Solving the equation for time

$$dt = \frac{W}{c_{D_o} S_o \sigma \frac{\rho_o}{2} g} \frac{\overline{dv}}{v^2}$$

wherein $\sigma \rho_o = \rho$ = density at the altitude considered. The ratio σ is plotted in Figure 5-3-2. By integrating, the time to decelerate from the initial speed v_1 to the final velocity v_2 is found to be

$$t = \frac{W}{c_{D_o} S_o \sigma \frac{\rho_o}{2} g} \left(\frac{1}{v_2} - \frac{1}{v_1}\right)$$

From this equation the deceleration is found to be

$$\frac{\overline{dv/dt}}{g} = \frac{1}{W} c_{D_o} S_o \sigma \frac{\rho_o}{2} v^2$$

Replacing the drag term by the speed differential

$$\frac{\overline{dv/dt}}{g} = \frac{v^2}{g^t} \left(\frac{1}{v_2} - \frac{1}{v_1}\right)$$

The deceleration is maximum at the beginning of the manouver, where $v = v_1$; hence

$$\frac{(\overline{dv/dt})\,max}{g} = \frac{v_1/v_2}{g^t} (v_1 - v_2)$$

The maximum force corresponding to this equation is important for the structural strength of both the parachute canopy and the aircraft or missile. It is to be noted that the last two equations are independent of altitude and density. The chart in Figure 5-6-1, by presenting numerical solutions of the last equation, serves to determine the maneuver to be performed by the aircraft. Theoretically, the acceleration of gravity g decreases with altitude. However, at 70,000 ft. altitude, the value of g has only decreased by 1/2 percent. After selecting value and time of deceleration, the parachute canopy size is determined as follows

$$S_o = \frac{W}{c_{D_o} \sigma \frac{\rho_o}{2} tg} \left(\frac{1}{v_2} - \frac{1}{v_1}\right)$$

The corresponding parachute canopy diameter is then

$$D_o = \sqrt{\frac{8}{\pi g \rho_o}} \sqrt{\frac{1}{\sigma}} \sqrt{\frac{W}{t\, c_{D_o}} \left(\frac{1}{v_2} - \frac{1}{v_1}\right)}$$

wherein the first root term is equal to 1/6.5 and the value for $\sqrt{1/\sigma}$ may be obtained from Figure 5-3-2. The chart in Figure 5-6-2 presents a solution of the last equation for a FIST ribbon type parachute canopy having a drag coefficient $c_{D_o} = 0.5$.

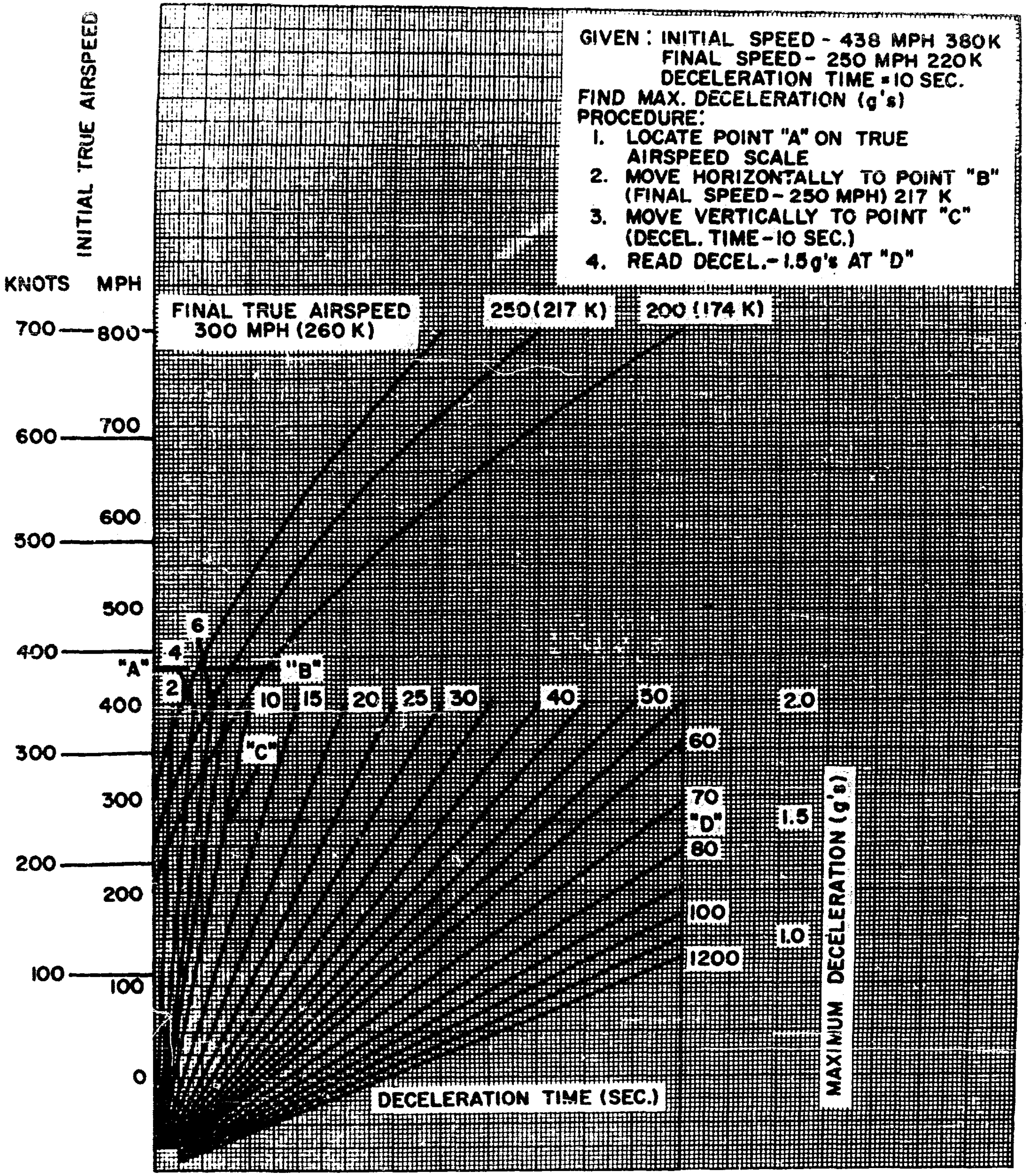


Figure 5-6-1. Determination of Deceleration Maneuvers of Aircraft

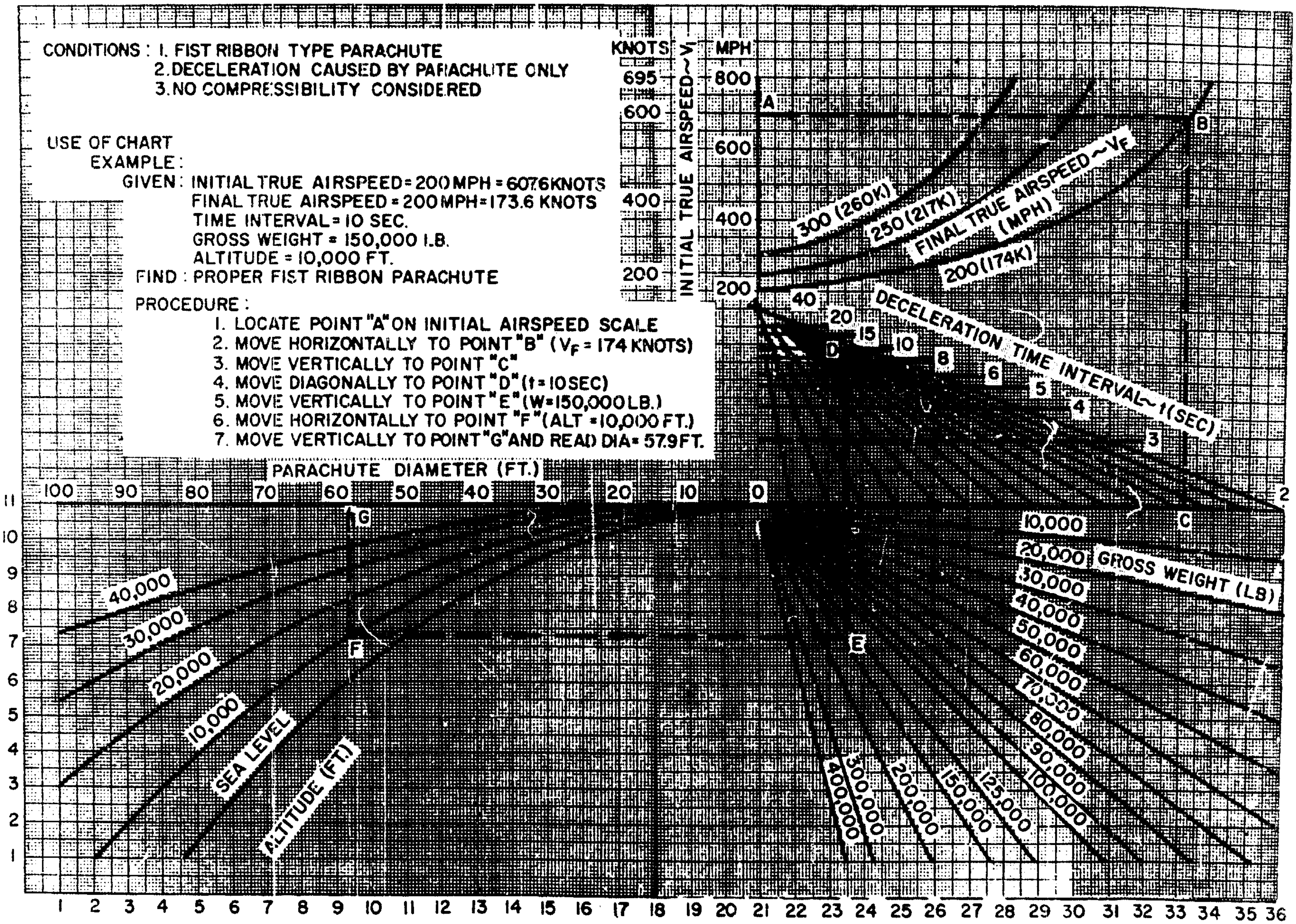


Figure 5-6-2. Selection Chart for Emergency Deceleration Parachutes

6.3 SAMPLE CALCULATION FOR FIRST STAGE MISSILE RECOVERY APPLICATION.

For this sample calculation, the following characteristics were chosen:

Weight (including recovery parachutes)	$W = 3580$ lb.
Speed at instant of suspension line stretch	$v_s = 700$ knots $= 1182$ ft./sec.
Altitude (constant)	$H = 30000$ ft.
Deceleration limit	$g = 5$

A desired parachute canopy type is selected from Chapter II governed by the following factors:

a. Capable of operation at low supersonic deployment speeds
b. Reliable operation
c. Good stability
d. Low opening shock
e. Minimum bulk and weight
f. Minimum manufacturing cost.

Maximum parachute packing volume available is approximately 2500 cubic inches. Based upon these factors, the choice is made to use a FIST Ribbon type canopy for this application. Not considering any possible influence of compressibility, the drag coefficient of this parachute canopy type is $c_{D_o} = 0.5$. It will also be assumed that the deceleration essentially takes place at constant altitude (of 30,000 ft.) with $\sigma = 0.37$ as found in Figure 5-3-2. Using equation

$$\frac{\overline{dv/dt}}{g} = \frac{1}{W} c_{D_o} S_o \sigma \frac{\rho_o}{2} v_s^2$$

the maximum deceleration is found to be

$$\frac{\overline{dv/dt}}{g} = 5 = \frac{0.5 \cdot 0.37 \cdot 0.002378 \cdot (1182)^2}{3580 \cdot 2} S_o$$

The required area of the canopy drag producing surface is then $S_o = 58.246$ ft.^{2} and the diameter is $D_o = 8.61$ ft.

6.3.1 OPENING SHOCK FORCE OF PARACHUTE CANOPY.

$$F_o = c_{D_o} S_o \sigma \frac{\rho_o}{2} v_s^2 x$$

wherein $c_{D_o} S_o$ = Drag Area = 29.123 ft^2

x = Opening Shock Factor = 1.1

$$F_o = 29.123 \cdot 0.37 \cdot 0.001189 \cdot (1182)^2 \cdot 1.1 = 19688 \text{ lb.}$$

6.3.2 INSTANTANEOUS CANOPY LOADING.

$$\frac{F_o}{c_{D_o} S_o} = \frac{19688}{29.123} = 676 \text{ lb/ft.}^2$$

6.3.3 REQUIRED CANOPY POROSITY. Required total porosity for the drag producing surface is chosen from Figure 5-13-15. For this low supersonic brake application and a canopy diameter $D_o = 8.61$ ft., the total porosity required will be approximately $\lambda_t = 19\%$.

6.3.4 REQUIRED SUSPENSION LINE STRENGTH. From Table 1, paragraph 3.2.4, Chapter V, the design factor for missile and capsule recovery, deceleration stage application is recommended to be

$$\text{Design Factor (Nylon)} = \frac{j}{u \cdot o \cdot e \cdot k} = 2.77$$

The total design strength for all suspension lines is therefore

Design Strength of Suspension lines $= F_o \cdot c \cdot$ Design Factor

wherein $c = 1.055$ for an assumed line length ratio $l_s/D_o = 1$

F_o = Opening Shock Force = 19688 lb.

Design Strength of Suspension lines $= 19688 \cdot 1.055 \cdot 2.77 = 57535$ lb.

6.3.5 REQUIRED NUMBER OF GORES IN THE DRAG PRODUCING SURFACE. No systematic approach has as yet been established to determine the number of gores required in any particular type of drag producing surface. However, experience has shown that the following approach will yield sufficiently accurate design data.

As a first approach toward the determination of number of gores required in a drag producing surface, one may add the value of the determined canopy diameter, in this case "8", and the number "4", which gives "12". Every effort should be made to arrive at a figure divisible by "4" in order to balance the forces transmitted from the drag producing surface to the suspended load and to make suspension line

connections to the risers easier. An increase in the number of gores will yield higher canopy stability, decrease strength requirements for individual lines, fabric, or ribbons, but may result in increased bulk and weight of the canopy. Here, a compromise will have to be made.

For the purpose of this example the gore number selected is "12", since only limited packing volume is available and canopy stability is considered sufficient. The individual suspension line design strength required is then

$$\text{Design Suspension line Strength} = \frac{57536}{12} = 4795 \text{ lb.}$$

A webbing suitable for suspension line use having a breaking strength of 4800 lb. is not standard; consequently, a somewhat stronger line, which is standard, will have to be chosen. From Section 8, Parachute Materials, one finds a woven nylon webbing, Specification MIL-W-4088B, Type XVIII, having a breaking strength of 6000 lb. This webbing is chosen.

6.3.6 GORE DIMENSIONS. Having established the required canopy drag area, the canopy diameter, and also the number of gores, the overall gore dimensions can now be established.

The constructed diameter D_c of the drag producing surface is

$$D_c = \sqrt{\frac{4 \cdot S_o}{\pi_o}}$$

wherein S_o = 58.246 ft.^{2} = 8388 inch^2
π_o = Polygon Shape Factor = 3.00 (From Table II, par. 3.25, Chapter V)

$$D_c = \sqrt{\frac{4 \cdot 58.246}{3.00}} = 8.81 \text{ ft.}$$

$$= 105.72 \text{ inch} \approx 105\ 3/4 \text{ inch}$$

The gore base width is then

$$e_g = D_c \sin\frac{\beta}{2}$$

wherein $\beta = \frac{360°}{n} = \frac{360°}{12} = 30°$ (enclosed gore angle)

$$e_g = 8.81 \cdot 0.2588 = 2.28 \text{ ft.} = 27.36 \text{ inch} \approx 27\ 3/8 \text{ inch}$$

and the height of the gore (to apex)

$$h_g = \frac{D_c}{2} \cos\frac{\beta}{2} = \frac{8.81}{2} \cdot 0.9659 = 4.25 \text{ ft.} = 51 \text{ inch}$$

For this relatively small parachute canopy the total vent area is assumed to be 1% of the constructed area of the drag producing surface. This relatively large value was chosen due to the fact that a major portion of the vent will be covered by the vent bands. Therefore, the vent diameter d_v = 10.57 inch ≈ 10 1/2 inch.

The gore width at the vent is

$$e_{g_o} = d_v \sin\frac{\beta}{2} = 10.57 \cdot 0.2588 = 2.73 \text{ inch} \approx 2\ 3/4 \text{ inch}$$

In order to relieve high stresses in the vent area, fullness is added. Experience has shown that for canopies with high instantaneous canopy loading, fullness in the vent area should be approximately 10%; thus

$$e_{g_v} = 1.1 \cdot e_{g_o} = 1.1 \cdot 2.73 = 3.00 \text{ inch}$$

Shortening of the vent lines relative to the vent diameter creates an effective fullness on the upper lateral band and reduces the load in the band, which is desirable. A vent line reduction of 14% is recommended, again due to the intended canopy application. For lower instantaneous canopy loadings, vent line reductions as low as 7% are used.

$$\begin{aligned}\text{Free vent line length} &= d_v - 0.14\, d_v \\ &= 10.57 - 1.48 \\ &= 9.09 \text{ inch} \approx 9.0 \text{ inch}\end{aligned}$$

Now the actual constructed height of the gore can be determined. It is

$$\begin{aligned}h_a &= h_g - \frac{dv}{2} \cos\frac{\beta}{2} \\ &= 51.0 - (5.285 \cdot 0.9659) \\ &= 51.0 - 5.10 = 45.90 \text{ inch} \approx 46 \text{ inch}\end{aligned}$$

6.3.7 GORE DETAILS. (See Figure 5-6-3.) The first step in definitizing details of the gore is to select a suitable horizontal ribbon. According to Figure 3-3-3, and based upon an established gore base width e_g = 2.28 ft. and a calculated instantaneous canopy loading of 676 lb./ft.^{2}, horizontal ribbons of 1000 lb. tensile strength are required. Therefore, nylon ribbons, Spec. MIL-R-5608B, Class E, Type II, 1000 lb. tensile strength, are chosen. The width of these ribbons is 2.0 inch.

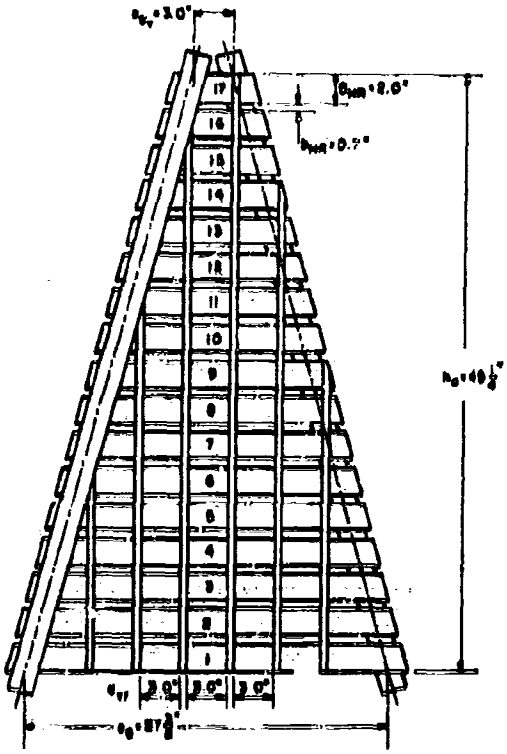


Figure 5-6-3. Gore Details, FIST Ribbon Type Parachute Canopy, 8.61 ft. Diameter

Since the mechanical porosity λ_m of 1000 lb. nylon ribbons can be considered to be zero, the required geometrical porosity λ_g is equal to the total porosity required

$$\lambda_g = \lambda_t = 19\%$$

In order to compensate for the loss of porosity effected by the radial ribbons, vent ribbons, and to correct for the increased porosity obtained from the vent, a correction factor for the required porosity is determined. This value, λ_a, is obtained from Figure 5-3-17 and added to the established value for λ_g. For a canopy diameter of $D_0 = 8.61$ ft., the correction factor is $\lambda_a = 2.45$. Therefore, the corrected porosity (actual) is

$$\lambda_{g_a} = \lambda_g + \lambda_a = 19 + 2.45 = 21.45\%$$

Vertical ribbons are added mainly to maintain ribbon spacing. A vertical tape, 9/16 inch wide, Spec. MIL-T-5038, TAPE, Nylon, Reinforcing, is chosen. Since this parachute canopy is to be used for first stage missile deceleration, and the canopy is required to open rapidly, a vertical ribbon spacing of 3.0 inches is selected (according to par. 3.2.10, Chapter V).

Based upon the above data, the gore details can now be finalized. Knowing the widths of the horizontal and vertical ribbons, the vertical ribbon spacing, and the actual geometric porosity of a ribbon grid:

$$B_{HR} = 2.0 \text{ inch}$$
$$A_{VR} = 0.625 \text{ inch}$$
$$a_{VR} = 3.0 \text{ inch}$$
$$\lambda_{g_a} = 21.45\%$$

The horizontal ribbon spacing b_{HR} can be determined from Figure 5-3-18 to be $b_{HR} = 0.7$ inch.

The number of horizontal ribbons required may be determined from

$$h_a = t\,(B_{HR} + b_{HR}) - b_{HR}$$

or

$$t = \frac{h_a}{B_{HR} + b_{HR}} + b_{HR} = \frac{45.9}{2.0 + 0.7} + 0.7 \approx 17$$

This will require a redetermination of the actual gore height:

$$h_a = t\,(B_{HR} + b_{HR}) - b_{HR}$$
$$= 17(2.0 + 0.7) - 0.7 = 45.2 \text{ inch} \approx 45\ 1/4 \text{ inch}$$

All gore design details have now been determined and only material for the radial ribbons, skirt, and vent bands, has to be selected.

6.3.8 RADIAL RIBBON. For this parachute canopy, the suspension lines will be routed over the apex. The weight and bulk increase as compared to skirt suspended suspension lines is negligible, if at all detectable, because, for the latter construction, stronger radial tapes or ribbons have to be used, since these tapes or ribbons transmit the forces to the suspension lines. In general, the combined strength of the radial ribbons, reinforcement tapes, and suspension lines should be at least that of the individual suspension line. For this sample calculation, radial nylon ribbons of identical specification as those selected for the horizontal ribbons are selected. Two (2) ribbons will be used as radials in such a manner that the horizontal ribbons are sandwiched between them.

6.3.9 UPPER AND LOWER LATERAL BANDS (VENT AND SKIRT BANDS). In general practice,

the strength of the vent band should be at least equal to the strength of the suspension line used for canopy constructions in which the suspension lines are routed over the apex. For construction in which the suspension lines are connected to the skirt, more strength should be built into the vent band. Consequently, for this sample calculation, a vent band, 6000 lb. tensile strength, Spec. MIL-W-4088B, Type XIII, is selected.

The strength of the skirt band should be approximately equal to that of the suspension line chosen. Generally, however, for FIST Ribbon type canopies, a double ply skirt band is used, so that the ribbons again may be sandwiched between them. For this canopy, two nylon ribbons, 3600 lb. tensile strength, 1 3/4 inch wide, Spec. MIL-W-4088B, Type VIII, are selected.

6.3.10 RECALCULATION OF GEOMETRIC POROSITY. Since all gore dimensions have now been established, a redetermination of the actual geometric porosity of the parachute canopy should be made. This is accomplished by means of the following equation

$$\lambda_{g_{act.}} = \lambda_{g_a}\left[1 - \frac{2\,B_{HR}\,v_g\left(1 - \frac{d_v}{D_c}\right)}{\pi_o\,D_c}\right] + \left[\left(\frac{d_v}{D_c}\right)^2 (100 - \lambda_{g_a})\right] \text{(Percent)}$$

wherein

$\lambda_{g_a} = 21.45\%$ $v_g = 12$ gores $D_c = 105.72$ inch

$B_{HR} = 2.0$ inch $d_v = 10.57$ inch $\pi_o = 3.00$

$$\lambda_{g_{act.}} = 21.45\left[1 - \frac{2 \cdot 2 \cdot 12\left(1 - \frac{10.57}{105.72}\right)}{3.0 \cdot 105.72}\right] + \left[\left(\frac{10.57}{105.72}\right)^2 (100 - 21.45)\right]$$

$$\lambda_{g_{act.}} = 19.30\%$$

This calculation shows that the finished parachute canopy will have a geometrical porosity very close to the value initially determined to insure satisfactory performance.

6.3.11 POCKET BANDS. Pocket bands will be added to this canopy in order to aid canopy inflation. Since the strength of the pocket band must be at least 50% of the suspension line strength, a nylon webbing, 3600 lb. tensile strength, Spec. MIL-W-4088B, Type VIII, is selected. Dimensions for the pocket bands are obtained from Figure 5-3-19. The free length of the pocket band, based upon a 12-gore drag producing surface, is

$$L_a = l_a \cdot e_g = 0.14 \cdot 27.36 = 3.83 \text{ inch}$$
$$\approx 3\ 13/16 \text{ inch}$$

6.3.12 CANOPY DESIGN AND CONSTRUCTION DATA SHEETS. After all design data have been established, sketches or drawings showing design and construction details and a guide for construction steps should be prepared to aid in the actual canopy fabrication. The following pages have been included to aid in the preparation of a canopy specification.

6.4 CONSTRUCTION SEQUENCE, FIST RIBBON TYPE PARACHUTE CANOPY.

1. Assemble Gore (Figure 5-6-6)
2. Sew Vertical Seam (Figure 5-6-7)
3. Sew Radial Seam (Figure 5-6-8)
4. Construct Vent with Reinforcing Band (Figure 5-6-9)
5. Construct Vent Reinforcing Band Overlap (Figure 5-6-10)
6. Construct Skirt with Reinforcing Band (Figure 5-6-11)
7. Construct Skirt Reinforcing Band Overlap (Figure 5-6-12)
8. Layout Suspension Line Material and Cut to Size (Figure 5-6-13)
9. Attach Suspension Lines (Figure 5-6-14)
10. Layout Pocket Band Material, Cut to Size and Attach (Figure 5-6-15)
11. Tie and Sear all Zig-Zag Stitching

ITEM	NAME	PLY	WIDTH	TENSILE STRENGTH	SPECIFICATION
1	Horizontal Ribbon	1	2"	1000 lb.	MIL-R-5608B
2	Radial Ribbon	2	2"	1000 lb.	MIL-R-5608B
3	Vertical Ribbon	2	9/16"	500 lb.	MIL-T-5038
4	Radial Seam Reinforcing Webbing	0			
5	Skirt Reinforcing Band	2	1-3/4"	3600 lb.	MIL-W-4088B
6	Vent Reinforcing Band	1	1"	6000 lb.	MIL-W-4088B
7	Vent Line	1	1"	6000 lb.	MIL-W-4088B
8	Suspension Line	1	1"	6000 lb.	MIL-W-4088B
9	Pocket Band	1	1-3/4"	3600 lb.	MIL-W-4088B
10	Thread		FF 3 cord 5 cord	16.0 24 40	MIL-T-7807
11	Glue, Rubber Cement				

Appr. Volume of Canopy: 3150 Cubic inches

Appr. Weight of Canopy: 22.5 pounds

Figure 5-6-4. Material Data Sheet, FIST Ribbon Type Parachute Canopy

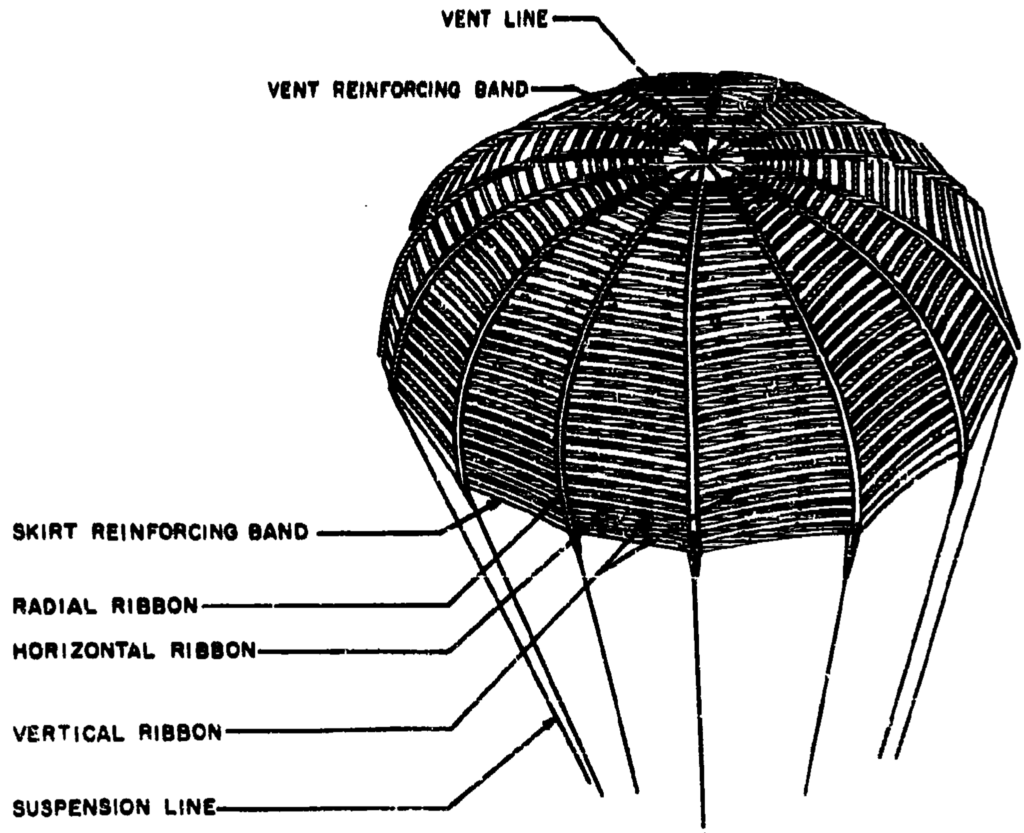


Figure 5-6-5. Component Parts for FIST Ribbon Parachute Canopy

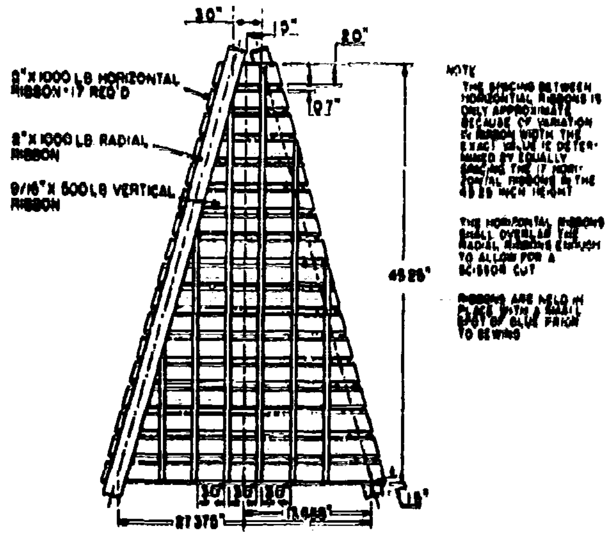


Figure 5-6-6. Gore Assembly, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

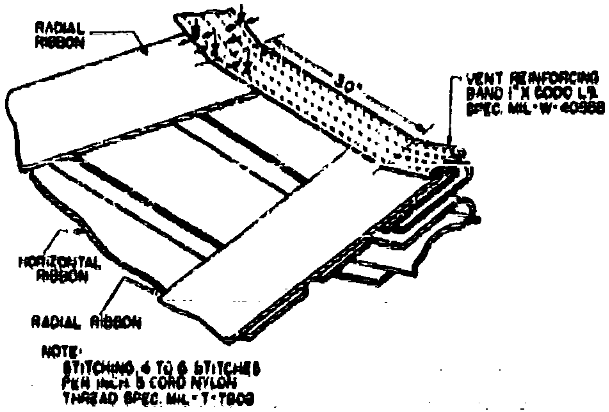


Figure 5-6-9. Exploded View of Vent Construction, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

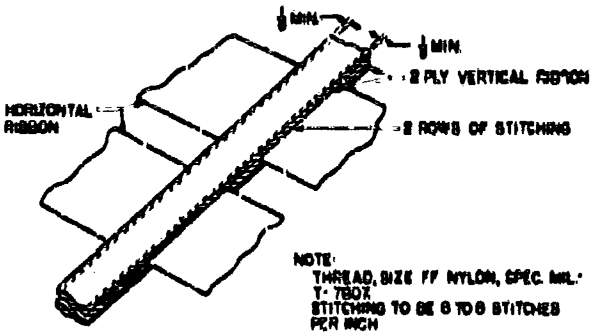


Figure 5-6-7. Vertical Ribbon Seam, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

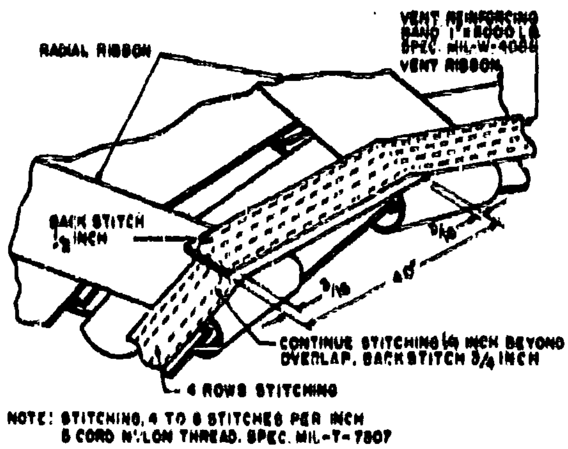


Figure 5-6-10. Vent Reinforcing Band, Overlap Stitching Detail, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

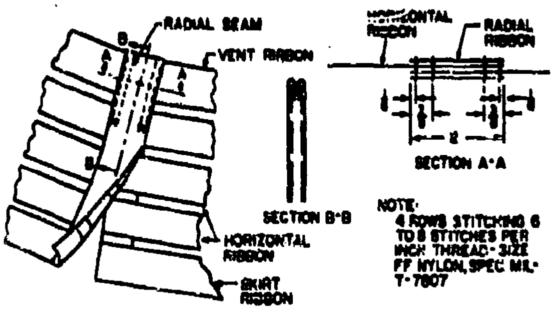


Figure 5-6-8. Radial Seam Construction, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

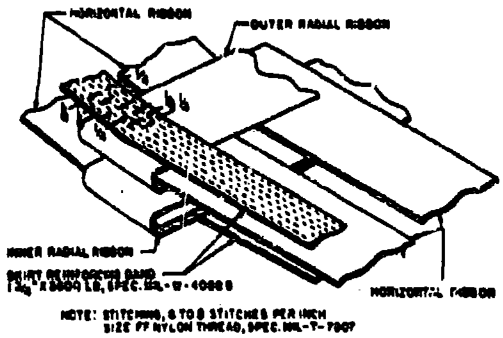


Figure 5-6-11. Exploded View of Skirt Construction, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

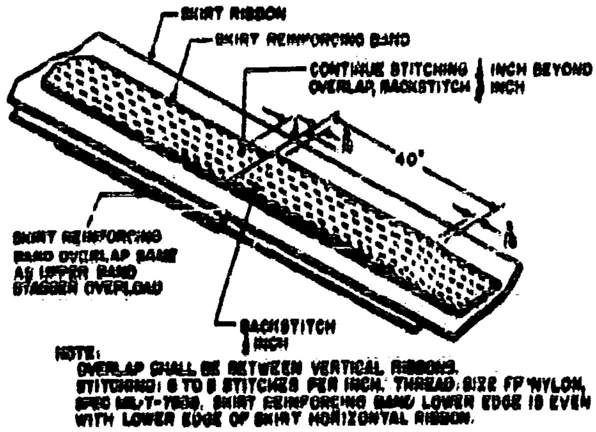


Figure 5-6-12. Skirt Reinforcing Band, Overlap Stitching Detail, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

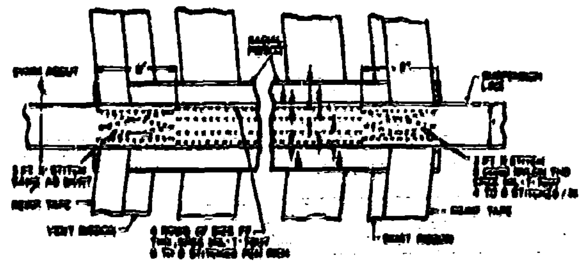


Figure 5-6-13. Suspension Line and Line Markings, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

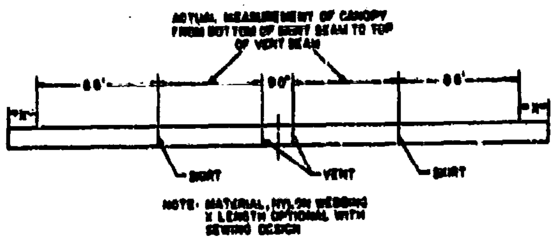


Figure 5-6-14. Suspension Line Attachment, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

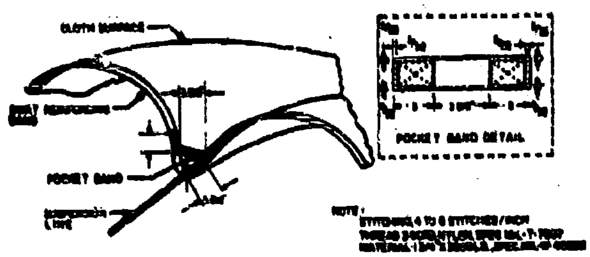


Figure 5-6-15. Pocket Band and Stitching, FIST Ribbon Type Parachute Canopy 8.61 Ft. Diameter

CHAPTER VI

ACCESSORIES AND CONTROL DEVICES

During the past few years, the scope of parachute applications and the range of speed and altitude at which parachutes must operate have increased tremendously. In many cases, high-altitude high-speed parachute applications require the use of automatic opening devices, which initiate parachute canopy deployment automatically after the recoverable body has decelerated for a predetermined time interval or has descended to a desired altitude. High-altitude high-speed recovery may also require the use of delayed actuating devices. Often canopy reefing systems are used, requiring electrically, mechanically, or pyrotechnically operated reefing devices. Multistage recovery systems require automatic devices to initiate or control deployment at each stage. Automatic devices are necessary to release parachute canopies from the load after surface contact in order to prevent dragging or toppling of the load. Many aerial delivery and missile recovery systems require deceleration devices to decrease ground impact shocks.

The design and manufacture of parachute hardware and automatic devices is governed by many factors. Automatic devices used on personnel parachutes must be so designed that manual operation may be employed at any time during the operation. All devices must operate properly over a wide range of environmental conditions. In general, all devices must be small and should require only negligible maintenance or service. All automatic devices and hardware must be able to withstand, and continue to operate after being subjected to, high imposed gravitational forces.

CHAPTER VI

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4.1

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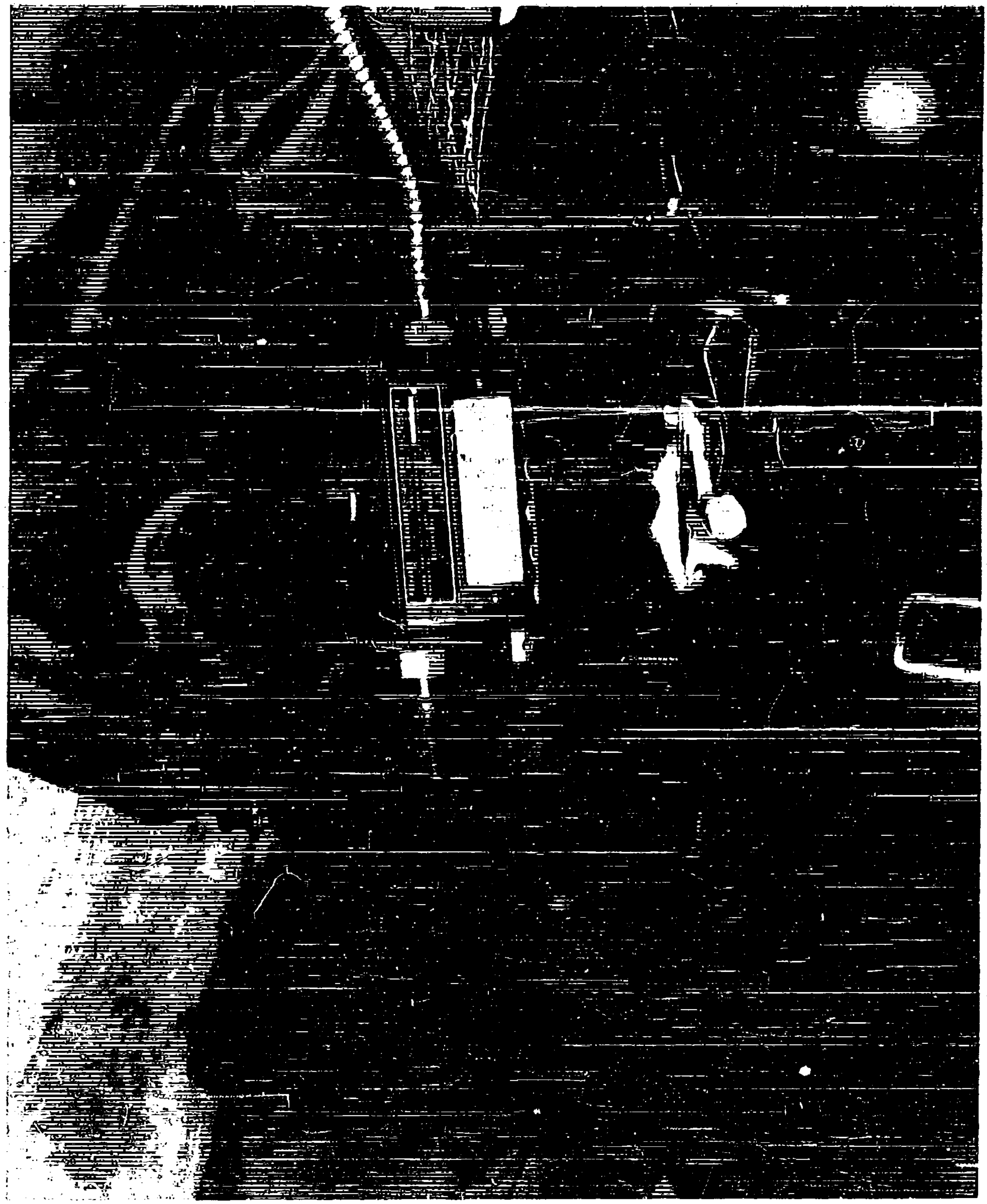


Frontispiece. Personnel Parachute Accessories

CHAPTER VI

SECTION I

PARACHUTE HARDWARE

1.1 GENERAL.

Parachute hardware in a broad sense is defined as all metal parts or assemblies that are used on the parachute. Many of these parts are employed in places where shape, type of material, and strength necessitate special design considerations. In general, parachute hardware material is determined by the particular application. During the period of parachute development, certain hardware items have become standard. In general, requirements for parachute hardware are outlined in Specification MIL-H-7195. Metals in contact with textiles must not produce oxides that will in any way affect the properties of the textiles. Most parachute hardware must be smoothly finished without protrusions that can in any way cause snagging, injury, or damage. Weight should be kept to a minimum consistent with the strength and safety factors required. On items to be used in quantity, cost of production must be a consideration. Of utmost importance, however, is the ability and reliability of the particular item to carry out its function.

1.2 PERSONNEL PARACHUTE HARDWARE.

Personnel parachute hardware may be placed into the following general categories:

a. Links.
b. Adapters.
c. Rings.
d. Snaphooks.
e. Release.

1.2.1 LINKS. Harness links are generally called "connector links." They form a rectangular shaped frame with a circular cross section and are used to connect the harness straps (risers) to the suspension lines of the canopy. All connector links now used are separable to facilitate quick harness or canopy replacement.

1.2.2 ADAPTERS. Adapters are rectangular shaped metal frames generally used to connect one harness strap to another, where routine disconnection of these straps is not required. Some adapters incorporate sliding friction bars to provide an adjustment point in the strap system.

1.2.3 RINGS. Harness rings are generally triangular or "D" shaped and are used primarily at the joining ends or closing points of the harness strap system. Strap ends having V rings or D rings generally join other strap ends having snaphooks or quick releasing hooks. D rings or V rings are also used at attachment points for the reserve parachute or accessory equipment.

1.2.4 SNAPHOOKS. Snaphooks are used as the releasable joining members to accomplish the connection of strap ends, reserve parachute, or accessories, to attachment points having D rings or V rings installed. Common types of snaphooks are operated or opened by depressing a hinged guard which allows the ring to disengage from the hook. Special types of snaphooks employ safety locks on the guard or ejecting type guards which facilitate quick disengagement of the hook from the ring.

1.2.5 RELEASES. Releases are the most complicated items of personnel parachute hardware. There are two basic types of releases, the harness release and the canopy release. The harness release, sometimes called quick release box, is used to collect and attach the restraining straps of the parachute harness to a central point on the body. Manual actuation of this release box enables the wearer to simultaneously release several straps of the harness to accomplish divestment. The canopy release is used to jettison the parachute canopy from its connection to the harness to prevent injury by dragging of the jumper along the ground during landing in high winds. Typical items of personnel parachute hardware described above are shown in Figure 6-1-1. Other items of hardware associated mostly with personnel parachute packs are generally familiar items, such as ripcords, housings, stiffeners, mounting plates, snap fasteners, zippers, grommets, and springs.

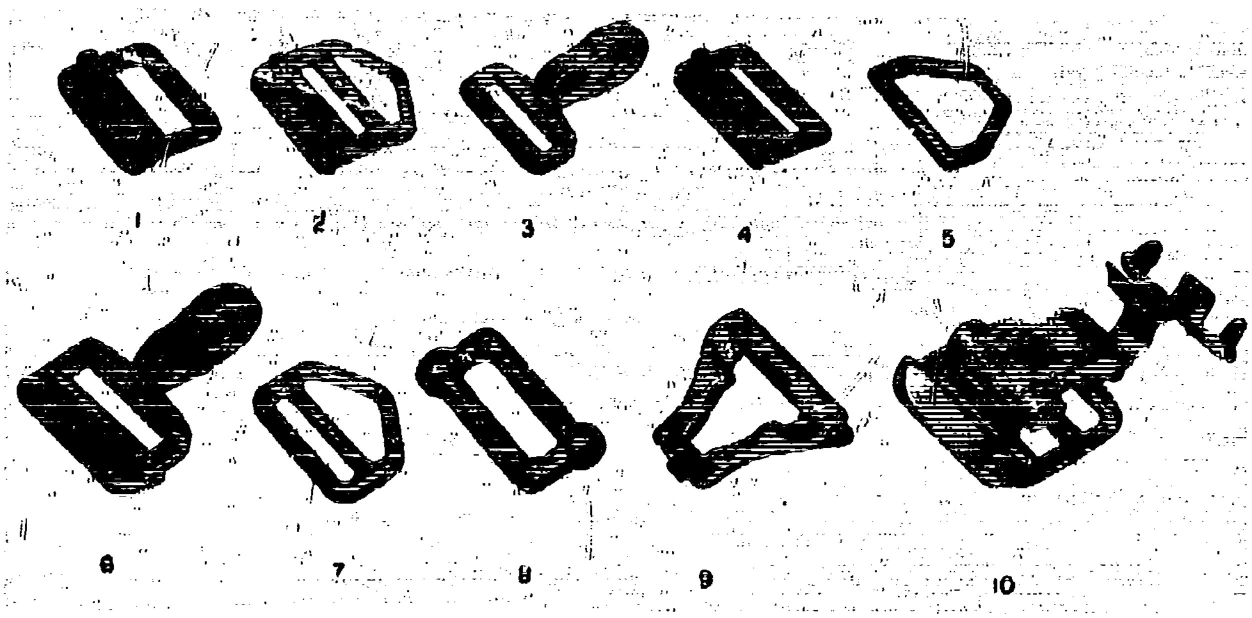


Figure 6-1-1. Typical Items of Personnel Parachute Hardware

1. Adapter, quick fit, parachute harness
2. Ring, V, quick fit, parachute harness
3. Snap, coiled spring, parachute harness
4. Adapter, quick fit, parachute harness
5. Ring, parachute harness, accessory attaching
6. Snap, quick fit, parachute harness
7. Link, connector, parachute harness
8. Link assembly, connector, replaceable parachute
9. Canopy release, male
10. Canopy release, female

1.3 AERIAL DELIVERY PARACHUTE HARDWARE.

Hardware for aerial delivery parachute systems is generally the same as that for personnel parachutes. Application, however, is generally different. See figure 6-1-2.

1.3.1 LINKS. Links are used for various purposes, including connecting parachute suspension lines to suspension webbings, connecting parachute deployment bags together in cases of parachute clustering, and connecting container webbings, which require separation capability for assembly and disassembly of fixed webbing lengths.

1.3.2 ADAPTER. Adjustable adapters are commonly used in connection with container webbings, which require adjustment for various container dimensions.

1.3.3 RINGS. Rings are generally used to connect container webbings to parachute snaphooks. V-shaped rings have been modified for the purpose of cutting retainer webbings, which secure containers and platforms to the aircraft until load release is desired.

1.3.4 SNAPHOOKS. Snaphooks are used as the releasable joining members to connect strap ends or accessories to attachment points having D rings or V rings attached. They are also used for attachment of static lines to the aircraft. Many aerial delivery parachutes are static-line deployed.

1.3.5 QUICK RELEASE. A quick release is used at the assembly closure point of container webbings to allow quick access to aerial delivery equipment, if required.

1.3.6 CLEVIS. Clevises are generally U shaped, incorporating a bolt through the open end for attachment purposes. Clevises are used primarily for the attachment of parachutes to loads. Various clevis sizes are used for load attachments capable of withstanding parachute opening forces for suspended loads in a range of between 100 and 25,000 pounds.

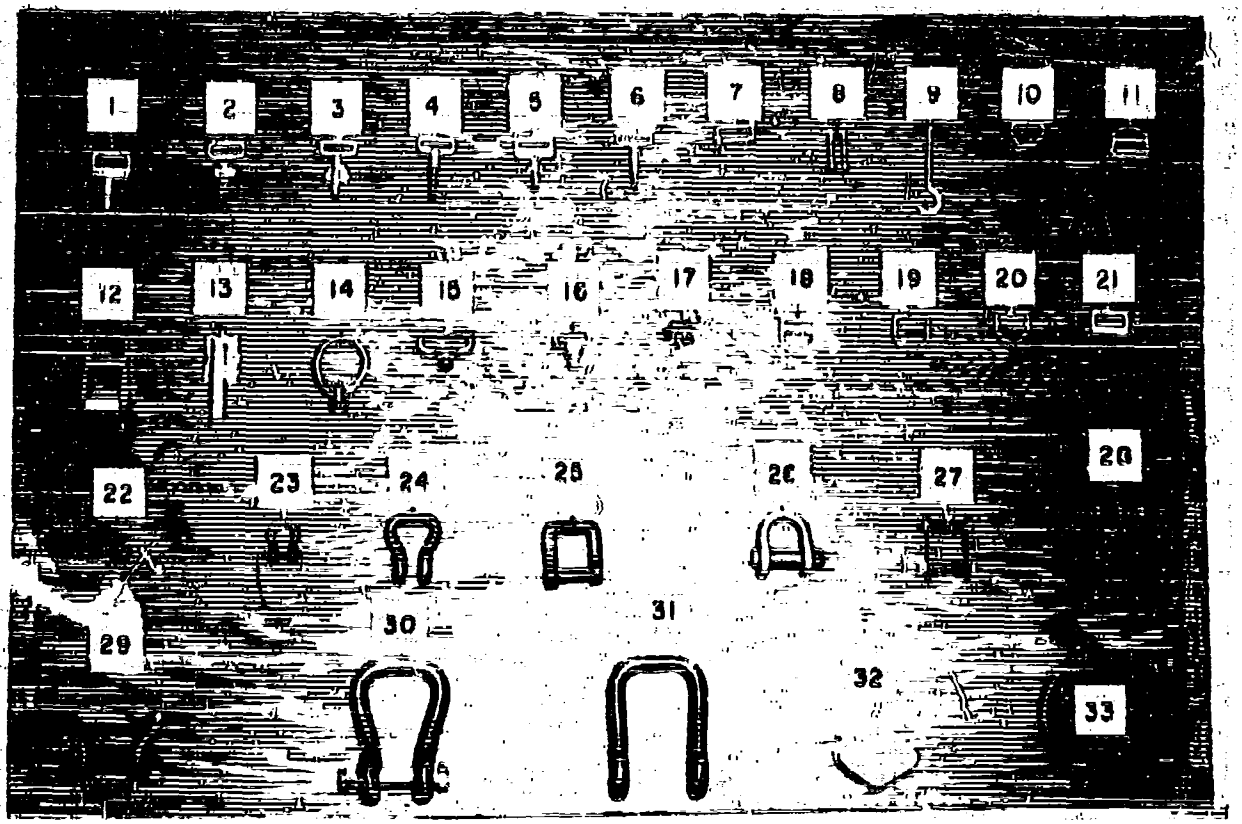


Figure 6-1-2. Typical Items of Aerial Delivery Parachute Hardware

1. Snap and friction adapter, quick fit, parachute harness, proof load 2,500 lbs. Used for tie-down, equipment
2. Snap assembly with flanges, parachute connector, proof load 5,000 lbs. Part No. 47D3138
3. Snap assembly with flange, proof load 5,000 lbs.
4. Snap assembly, general purpose, proof load 5,000 lbs.
5. Snap assembly, parachute connector
6. Snap assembly, general purpose, proof load 2,500 lbs.
7. Link assembly connector, replaceable parachute. Part No. 50B6869
8. Link assembly connector, replaceable parachute. Part No. 52B6660-1
9. Scuff board hook and screw, side buffer assembly. Part No. 51B6595
10. Ring, parachute accessory attaching. Part No. 44A9361
11. Ring, V, quick fit. Part No. 48B7055
12. Load, set weblock assembly
13. Cutter, reefing line
14. Ring, C-119 tie-down
15. Ring, C-119 tie-down. Part No. 4160528
16. Ring, shear web tie-down, C-119 aircraft
17. Clamp assembly, conveyor
18. Ring, parachute, D-drilled. Part No. 43A26411
19. Ring, parachute, D. Part No. 43B21549
20. Knife, shear web, modified V ring
21. Adapter, harness, quick fit
22. Clevis, static line, cargo parachute. Part No. 51B6719
23. Clevis, static line, cargo parachute
24. Clevis, small. Part No. 49B7459. Used W/C-1 aerial delivery kit
25. Clevis, M, not standard
26. Clevis, parachute aerial delivery kit. Part No. 51B6086
27. Link assembly, C-1 aerial delivery kit, single. Part No. 50B7456
28. Line assembly, aerial delivery kit, dual cluster. Part No. 50B7457
29. Clevis, aerial delivery. Part No. 51B6245
30. Clevis, aerial delivery. Part No. 49B7460
31. Clevis, large square
32. Plate, link platform aerial delivery. Part No. X51B6301 and X51B6330
33. Diaphragm, Air bag

CHAPTER VI

SECTION 2

PARACHUTE REEFING LINE CUTTER

2.1 GENERAL.

The need for a reduction of parachute canopy opening shocks and for canopies with controlled drag areas led to the development of reefed parachute canopies. At the same time, devices had to be developed which would accomplish the disreefing sequence. For this purpose, a number of disreefing devices were developed for different applications. These devices are operated either by means of pyrotechnics or by means of electrical impulses.

2.2 STANDARD REEFING LINE CUTTER, TYPE M-2.

The current standard method of disreefing a parachute canopy, when skirt reefing is used, is to cut the reefing line threaded through reefing rings around the skirt of the canopy. In general, pyrotechnic reefing line cutters are employed for this purpose. The reefing line cutter, type M-2, is shown in Figure 6-2-1. Removal of the arming wire (7) allows the firing pin (6) to initiate the time delay power train through a percussion cap (4). A powder charge is ignited by the powder train, causing the piston (3) to move. The reefing line is inserted into the housing (1) through a hole (2). A mounting plate (9) with clamp (10) is provided to facilitate installation of the device on the parachute canopy. The arming wire is generally connected to a suspension line. When the parachute is deployed, this arming wire is removed, starting the cutting sequence. In order to eliminate the possibility of premature release, the arming wire is designed with a safety device requiring the application of 25 pounds of tension prior to release, and also for some free travel before the firing pin actuates the device. This disreefing device is designed to cut lines of up to 1,000 pounds tensile strength. Time delays are available for intervals of 2, 4, 6, 8, or 10 seconds. In general, this device can be used only once, unless the entire assembly is returned to the manufacturer for reloading and rework.

2.3 STANDARD REEFING LINE CUTTER, TYPE MC-2.

For operation in reefing systems utilizing heavy reefing lines having a tensile strength of up to

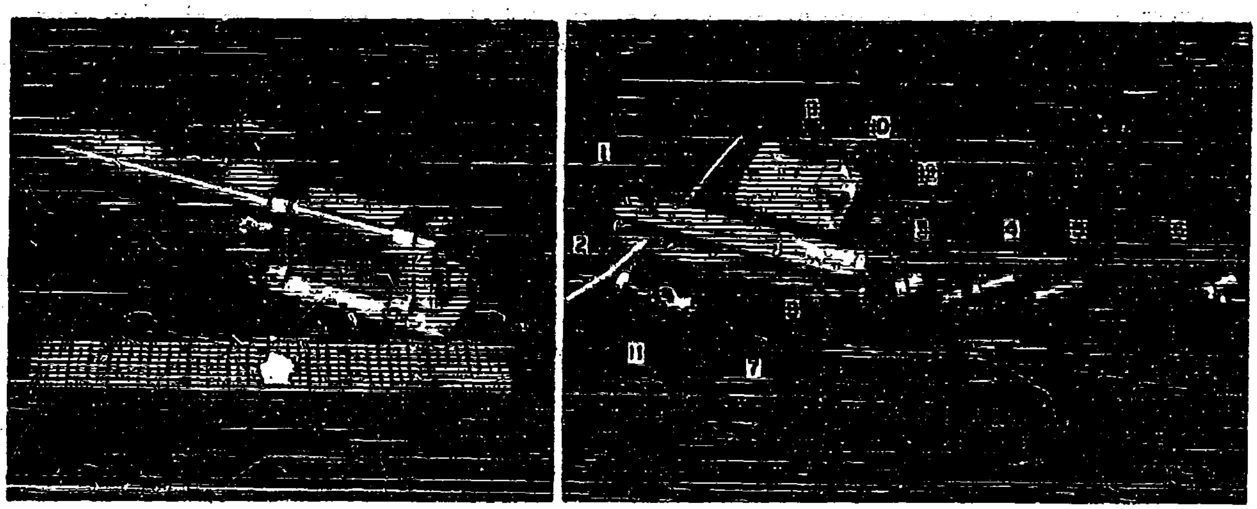


Figure 6-2-1. Reefing Line Cutter, Type M-2

14,000 pounds, a heavy duty device, type MC-2, has been developed and standardized. This device is shown in Figure 6-2-2. The type T-2 actuator and a delay powder train are utilized to actuate and govern the cutting sequence. Cutting of the reefing line is accomplished by means of a knife which is propelled by the powder charge. Actuation of the device is accomplished by the removal of an arming wire. This device can be reused merely by changing the time delay powder train. Time delays for intervals of 0.75, 1, 2, 4, 6, 8, and 10 seconds are available.

2.4 EXPERIMENTAL REEFING LINE CUTTERS.

A number of other types of disreefing devices have been used in the past or are under development. These devices either are actuated by electrical impulses or are completely mechanical. In designing a reefing line cutter, particular attention must be paid to the details given below.

2.4.1 The knife-shaped piston of the device must be longer than the diameter of the reefing line hole, in order that powder pressure cannot escape prematurely. Accurate dimensions of the cutter piston are important.

2.4.2 Sufficient space must be provided beyond the reefing line hole for a full stroke of the piston, so that the cut end of the reefing line can clear the remainder of the reefing line.

2.4.3 The powder charge must be well blocked off from the firing mechanism.

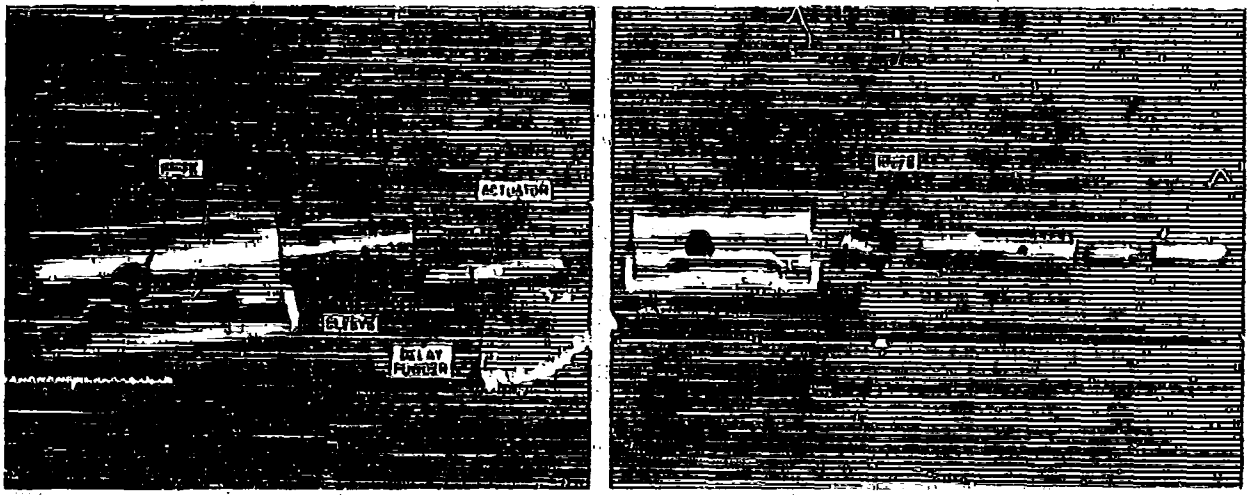


Figure 6-2-2. Reefing Line Cutter, Heavy Duty, Type MC-2

CHAPTER VI

SECTION 3

AUTOMATIC ACTUATING AND OPENING DEVICES

3.1 GENERAL.

Automatic actuating and opening devices are in general use for the operation of parachute systems for nearly all parachute applications. Actuating and release devices are primarily required for missile and aircraft deceleration parachute applications, while automatic parachute opening devices are now commonly employed in personnel and emergency escape parachutes.

3.2 PARACHUTE COMPARTMENT DOOR RELEASE.

The opening of the parachute compartment door, or release of the whole door, at high aircraft speeds, is essential in aircraft deceleration parachute application and for a successful missile or drone recovery operation. The problem is usually not as simple as it appears. The unlatching mechanism must function reliably under various environmental extremes, such as low temperatures (-65° F.), high altitude, acceleration, and vibration. The mechanism must not have an adverse effect on the performance of the aircraft or missile, such as adding extra drag in the airstream. Generally, the space allotted inside the vehicle for this device is small. For aircraft deceleration parachute application, actuating devices based on mechanical or solenoid principles are commonly used. For missile applications, explosive bolts have been used successfully. These bolts have taken various configurations, depending on the particular application, and have been put to other uses, such as opening landing bag hatches on missiles, or releasing wing tanks on a piloted aircraft. One feature which is common to all explosive bolt designs is that they are actuated by one or more electrically ignited explosive squibs. Two of the principles which have proven successful during actual operation are explained below.

3.2.1 EXPLOSIVE BOLT, SHEAR PIN TYPE. Figure 6-3-1 shows how an explosive bolt is used to separate a tail cone, containing a parachute, from the rest of the vehicle. The bolt installation is shown in Detail A of the drawing, and is also shown disassembled. The barrel, the squib, and the plug, which is held in place by the rivet, are attached to the airframe. The screw is inserted through a hole in the cone that is to be jettisoned, then screwed into the plug. With this type of installation, the head of the bolt is flush with the skin of the fuselage. When the squib fires, the plug shears the rivet, and the plug and screw are ejected, thus releasing the parachute.

3.2.1.1 In Figure 6-3-2, the body is secured to the airframe, and the piston is held in place by the shear pin. The parachute compartment cover is then held in place by the screw. This particular device is provided with two squibs, wired electrically in parallel for increased reliability. If only one squib fires, sufficient pressure is produced to shear the pin and eject the piston and screw. The dual squib arrangement is considered essential for reliable operation.

3.2.1.2 Figure 6-3-3 illustrates another dual squib explosive bolt using the shear pin principle. This particular bolt is used in a wing tank jettisoning system.

3.2.2 EXPLOSIVE BOLT — FRANGIBLE TYPE. Figure 6-3-4 shows this bolt, both assembled and disassembled. This particular bolt provides for only one squib, which is considered safe only if a large number of functional tests are made to prove the reliability; however, it illustrates a principle of operation. When the squib explodes, the internal pressures cause the bolt to fracture and break away at the section that has been weakened by undercutting. This releases the item that was being retained.

3.3 PARACHUTE CANOPY RELEASE.

Canopy release devices are commonly used for aircraft deceleration parachute and drone recovery parachute applications. The purpose of this device is to separate the canopy from the

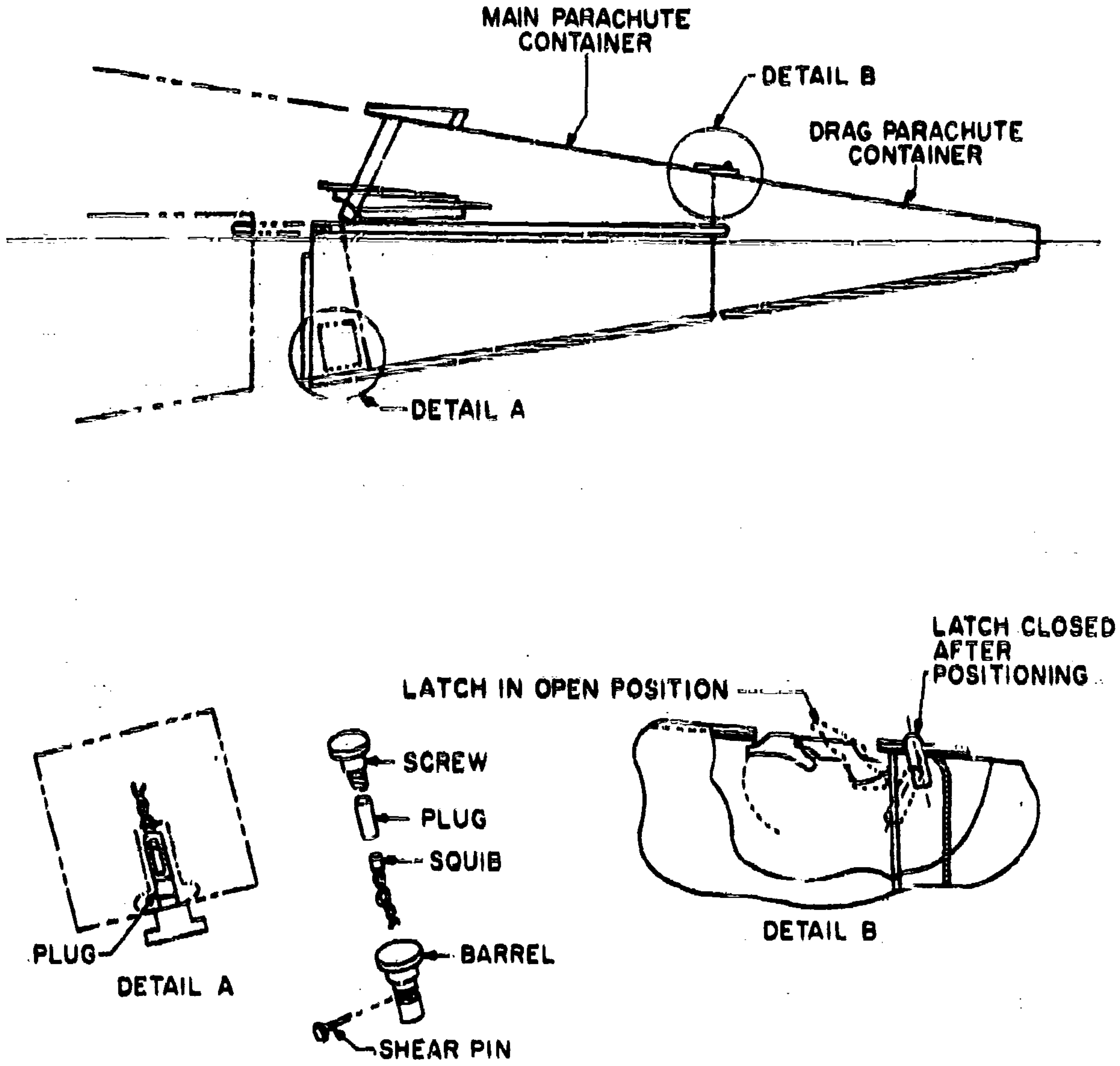


Figure 6-3-1. Explc 've Bolt — Shear Pin Type

vehicle after the landing deceleration or recovery mission has been accomplished. A variety of release devices have been tested and used, of which the most generally applied principles are described below.

3.3.1 PARACHUTE CANOPY RELEASE ASSEMBLY — SPRING-ACTUATED HOOK TYPE. Figure 6-3-5 shows a spring-actuated hook type release that has been used in drone recovery. While the drone is in flight, the spring S pushes ring R against pin P holding the pin in place. As the parachute is deployed, a load is placed on the ring and the ring and spring move to the position shown in Figure 6-3-5, at the same time relieving the friction between the

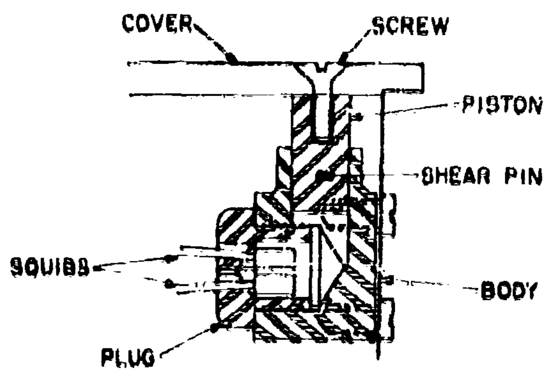


Figure 6-3-2. Explosive Bolt — Shear Pin Type

ring and pin. The pin is designed to fall free of the cylinder, when in a vertical position, approximately 10 seconds after release of the friction of the ring. When the vehicle touches the ground and the load is partially relaxed, the spring forces the ring off the then unobstructed hook, disconnecting the parachute canopy. Disadvantages of this design are that foreign matter in the cylinder may cause improper operation of the pin, and that the relaxation of the load caused by air currents may result in air separation of the load and parachute canopy.

3.3.2 PARACHUTE CANOPY RELEASE ASSEMBLIES — EXPLOSIVE SQUIB TYPE. The following three ground releases are actuated by electrically ignited explosive squibs. This is considered the most positive means of accomplishing the release action; however, an additional device is introduced into the operation. In order to fire the squibs, an electrical circuit must be closed when the vehicle strikes the ground. This has been accomplished in the most satisfactory manner to date by actuating a switch through the action of a feeler wire, which projects 3 to 6 inches beyond the bottom of the vehicle.

3.3.2.1 Parachute Canopy Release Assembly — Latch Type. Figure 6-3-6 shows a squib-actuated latch type parachute canopy release assembly. The parachute canopy is attached to the end link; the load is suspended from the latch. Actuation may be accomplished by a timer switch completing the squib circuit, an impact switch, a normally closed switch that is kept open by the load, a feeler wire switch, or any other switch arrangement that may be required for the particular application. Firing of either one of the squibs forces pin P to move the arm that rotates about O, breaking shear pin S and releasing the latch.

3.3.2.2 Parachute Canopy Release Assembly — Hook Type. Figure 6-3-7 shows a squib-operated hook type release. When squib S fires, the gas pressures exit through holes (1), travel down the air gap (2), and reenter holes (3), forcing the piston (4) up against the spring. The latch L is then released, permitting ring R to fall free. This device is still undergoing development.

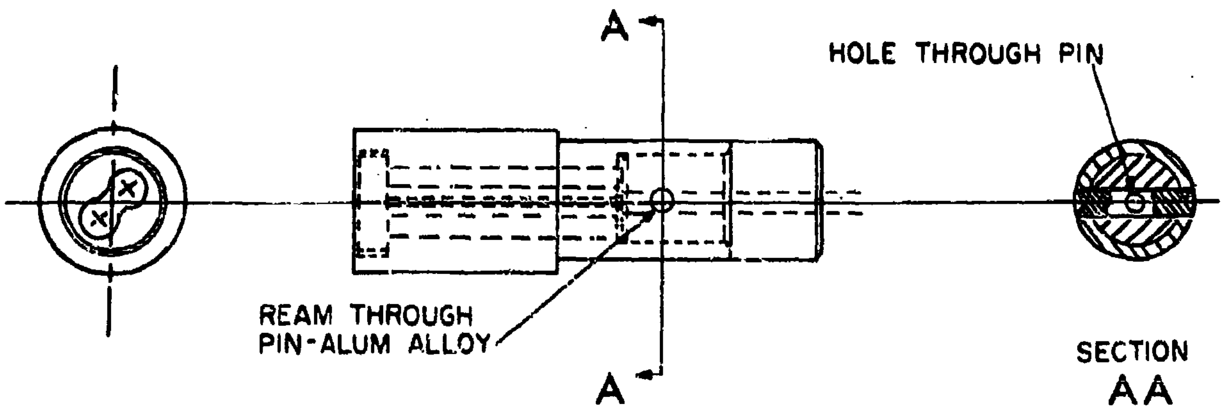


Figure 6-3-3. Tank Retaining Explosive Bolt Assembly

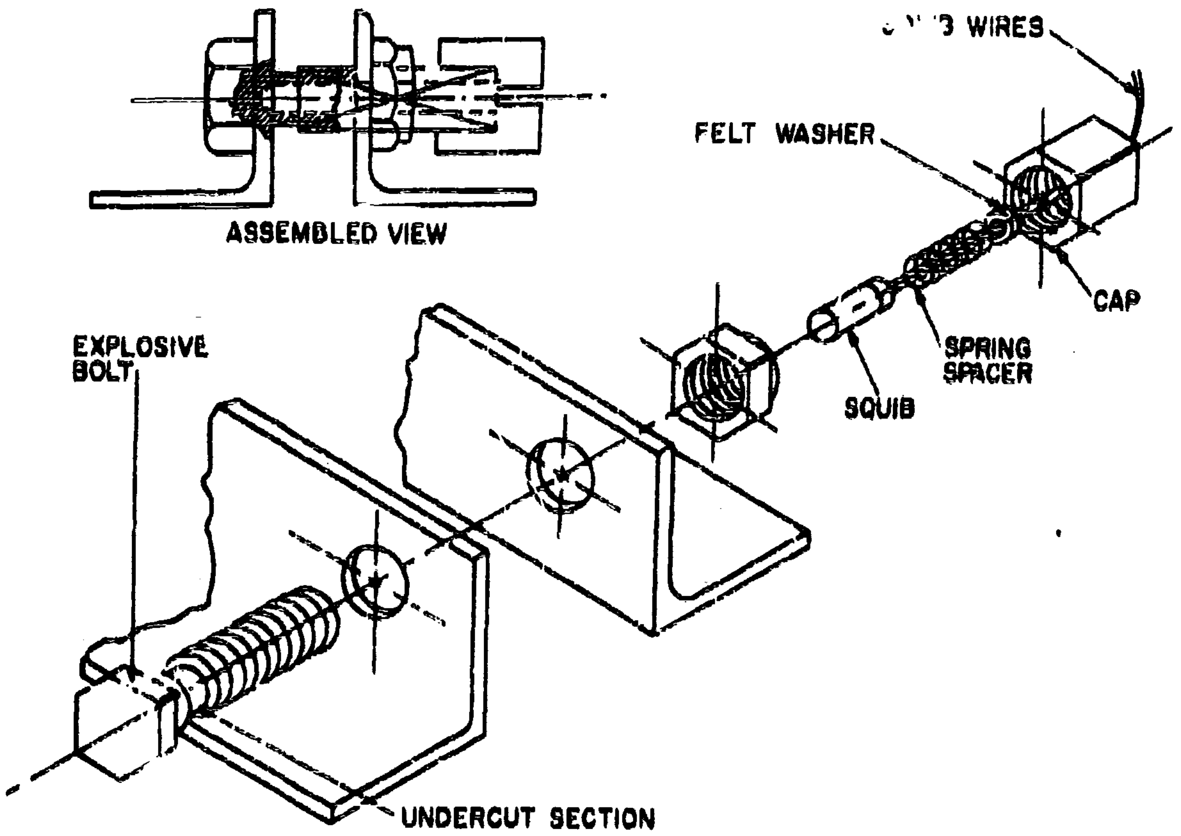


Figure 6-3-4. Explosive Bolt – Frangible Type

3.3.2.3 Disconnect Swivel – Squib-Operated. Figure 6-3-8 shows a squib-operated disconnect swivel. The left half of the drawing shows the plunger P in the unfired position, with the shear pin S in place. In this condition the load is transmitted from the cage C through the ball bearings B to the outer race R. When the squib fires, the plunger breaks the shear pin and moves to the positions shown on the right half of the drawing. This allows the balls to move inward, and the cage slips out of the outer race, thus disconnecting the parachute canopy.

3.4 AUTOMATIC PARACHUTE RIPCORD RELEASE.

3.4.1 PURPOSE. The advancement of operation of aeronautical equipment into high altitude and supersonic speed ranges has added requirements for automatic devices in emergency escape parachute systems. An automatic parachute ripcord release, type F-1A, was developed and standardized. When installed in a parachute pack, it pulls the parachute ripcord after elapse of a preset time interval and below a preset pressure altitude after timer actuation. Timer actuation may be manual or may be performed automatically during operation of emergency escape systems. Performance characteristics for the automatic parachute ripcord release are outlined in Military Specification MIL-R-6335E. The automatic parachute ripcord release, type F-1A, is shown in Figure 6-3-9. This release is housed in a case approximately 2 1/2 by 2 1/2 by 4 1/2 inches and weighs slightly over two (2) pounds.

3.4.2 OPERATION. The type F-1A release assembly consists of an arming cable assembly, an aneroid mechanism, and a coil-spring-operated timing mechanism, which also is the power source. When the knob to which the arming cable is attached is pulled, it extracts the arming pin from its seat against the trigger assembly. The trigger assembly, which in turn is sealed against the weighted escapement, is blocked by an inclined cam on the aneroid assembly. When the preset altitude is reached, the bellows contracts sufficiently to allow the trigger assembly to spring free of the inclined

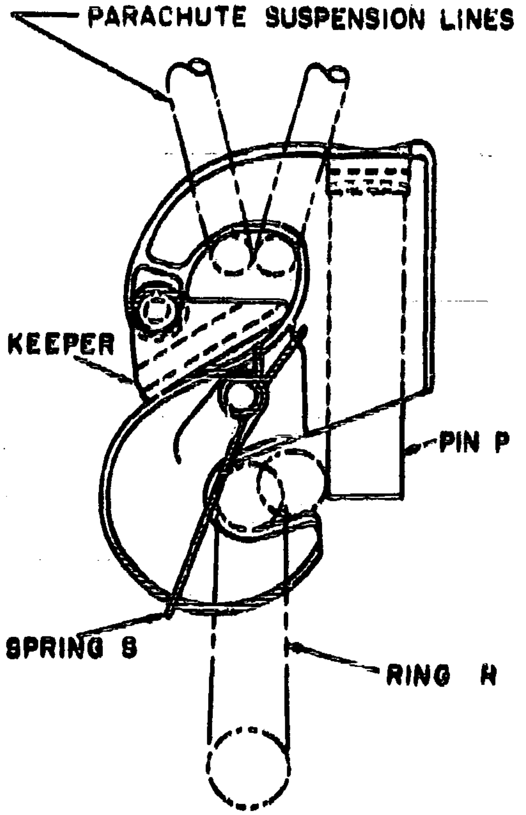


Figure 6-3-5. Parachute Canopy Release Assembly — Spring-Actuated Hook Type

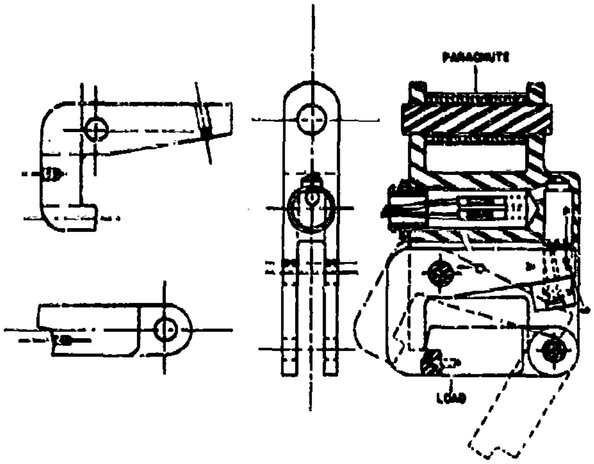


Figure 6-3-6. Parachute Canopy Release Assembly — Latch Type

cam, thus releasing the weighted escapement. The weighted escapement assembly, no longer restrained by the trigger assembly, permits the timer mechanism to operate. After a time lapse, preset on the timer mechanism, the remaining energy in the spring is released to the spool and cable assembly. As the spool is wound, it pulls on a cable, which is attached to the parachute ripcord cable, thus opening the parachute pack. The timer mechanism is wound by a special key. Since the automatic ripcord release withdraws the same set of ripcord pins as the manual release, there is no interference in any respect with ordinary manual operation. Figure 6-3-10 shows measured energy curves of the type F-1A automatic parachute ripcord release and measured energy curves in actual parachute pack operation.

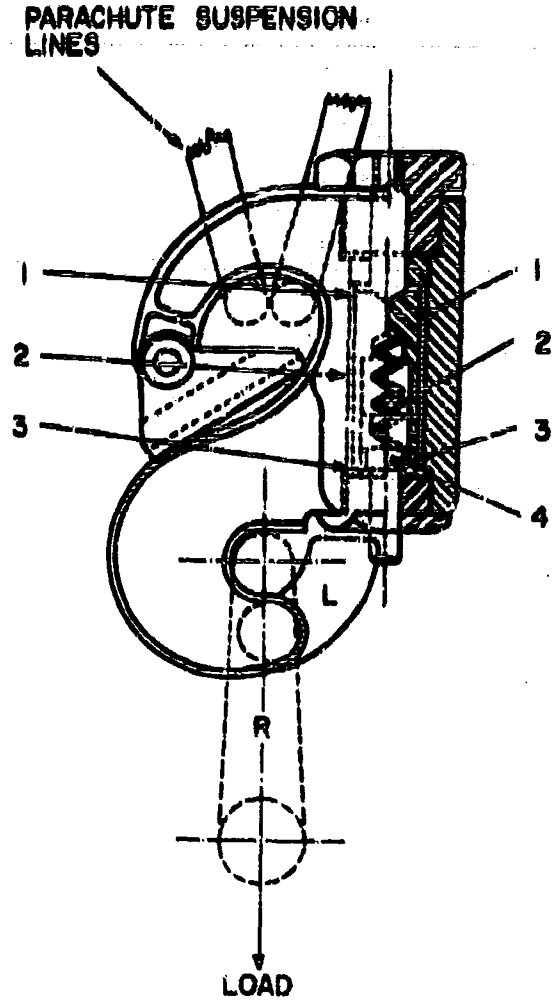


Figure 6-3-7. Parachute Canopy Release Assembly — Hook Type

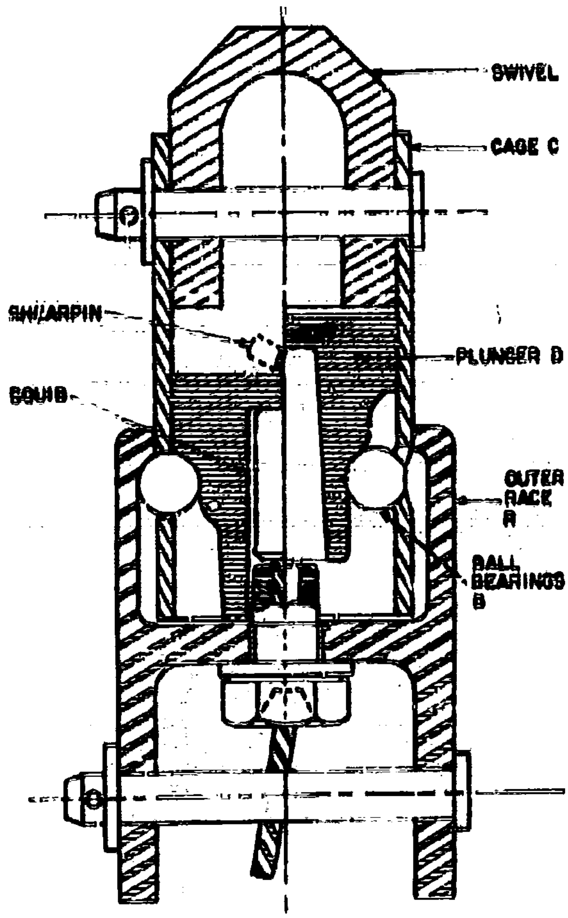


Figure 6-3-8. Disconnect Swivel — Squib Operated

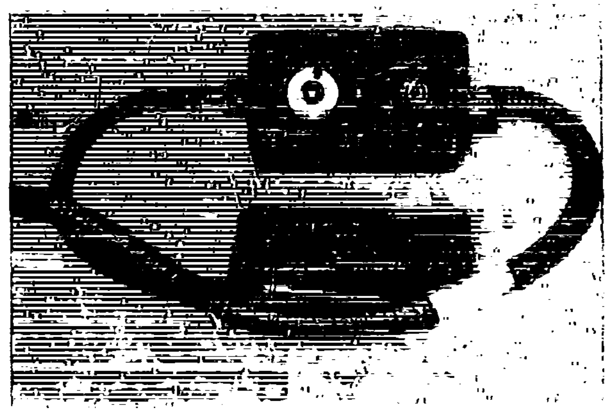
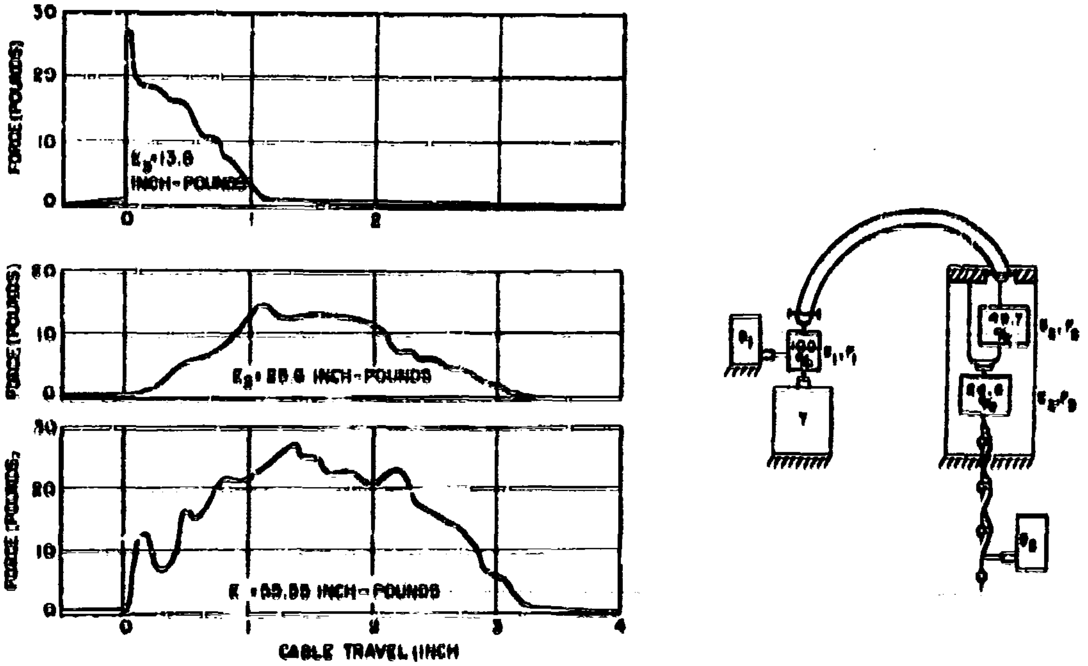


Figure 6-3-9. Automatic Parachute Ripcord Release, Type F-1A — Cover Removed



ENERGY DISTRIBUTION ON PARACHUTE PACK WITH F-1A TIMER, STANDARD PULLEY, STANDARD HOUSING, AND NORMAL BEND IN HOUSING

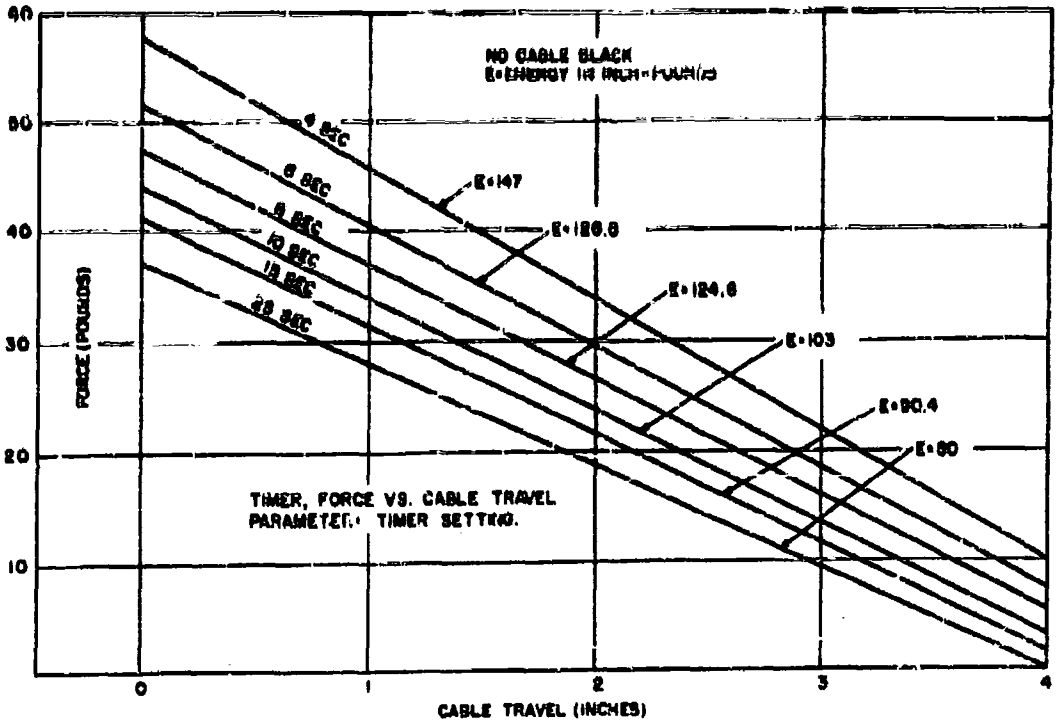


Figure 6-3-10. Type F-1A Automatic Parachute Ripcord Release, Energy Curves

CHAPTER VI

SECTION 4

PARACHUTE CANOPY GROUND DISCONNECTS

4.1 GENERAL.

Most types of aerial delivery and final stage recovery parachute canopies remain inflated under moderate wind velocities (10 knots or above), and tend to drag or overturn the suspended load after ground impact. Disconnects are used to automatically separate the parachute canopy or canopies from the load upon ground impact, thereby eliminating damage to the load after landing. Ground disconnects can be classified into four general design types: mechanical release, explosive actuated release, electrically actuated release, and combination of mechanical, explosive, and electrical release.

4.2 GROUND DISCONNECT DESIGN AND OPERATION.

Several types of ground disconnect designs, which have particular application for final stage recovery parachute systems, are discussed in Section 3 above. For aerial delivery parachute systems, standard disconnects used at the present time are of the mechanical type, such as that shown in Figure 6-4-1; however, for special applications an explosive or electrically actuated ground disconnect may be found more suitable. The avoidance of premature midair release during parachute canopy deployment and descent as well as a high degree of reliability of release at ground impact are of prime importance for any disconnect design. Integral time delay devices of various types have been found effective in eliminating premature load release during canopy deployment and descent. Standard disconnects depend upon the principle of load relaxation for separating the parachute canopy from the load after ground impact. Ground disconnects with a capacity range of from 200 to 500 pounds are available for aerial delivery of containers, and with a capacity range of from 1,000 to 5,000 pounds for aerial delivery of heavy cargo. If clusters of parachute canopies are used for aerial delivery parachute systems, one ground disconnect is used for each canopy. A ground disconnect based on explosive actuation and incorporating time delay is shown in Figure 6-4-2. Preparation of a mechanical heavy-capacity ground disconnect used in connection with type G-11A parachutes for aerial delivery is shown in Figure 6-4-3. Disconnects are designed to operate at a rate of load descent of up to approximately 30 feet per second combined with a horizontal wind velocity of up to 30 knots.

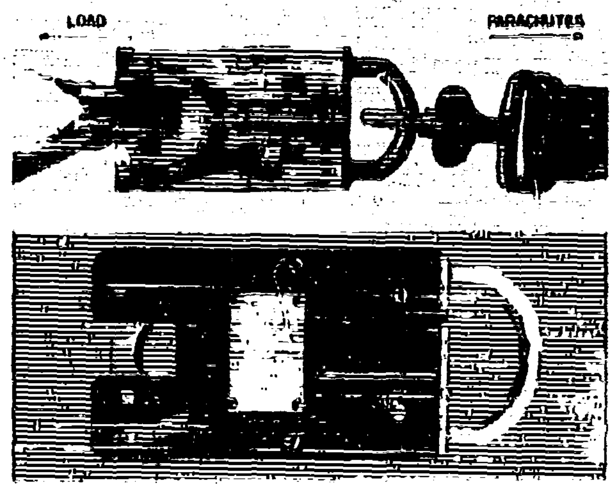


Figure 6-4-1. Parachute Canopy Ground Disconnect – Mechanical, Aerial Delivery Parachute System

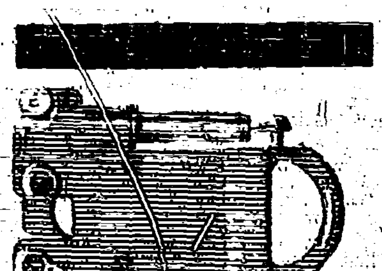


Figure 6-4-2. Parachute Canopy Ground Disconnect – Explosive Actuated, Aerial Delivery Parachute System, 500 Pounds Capacity

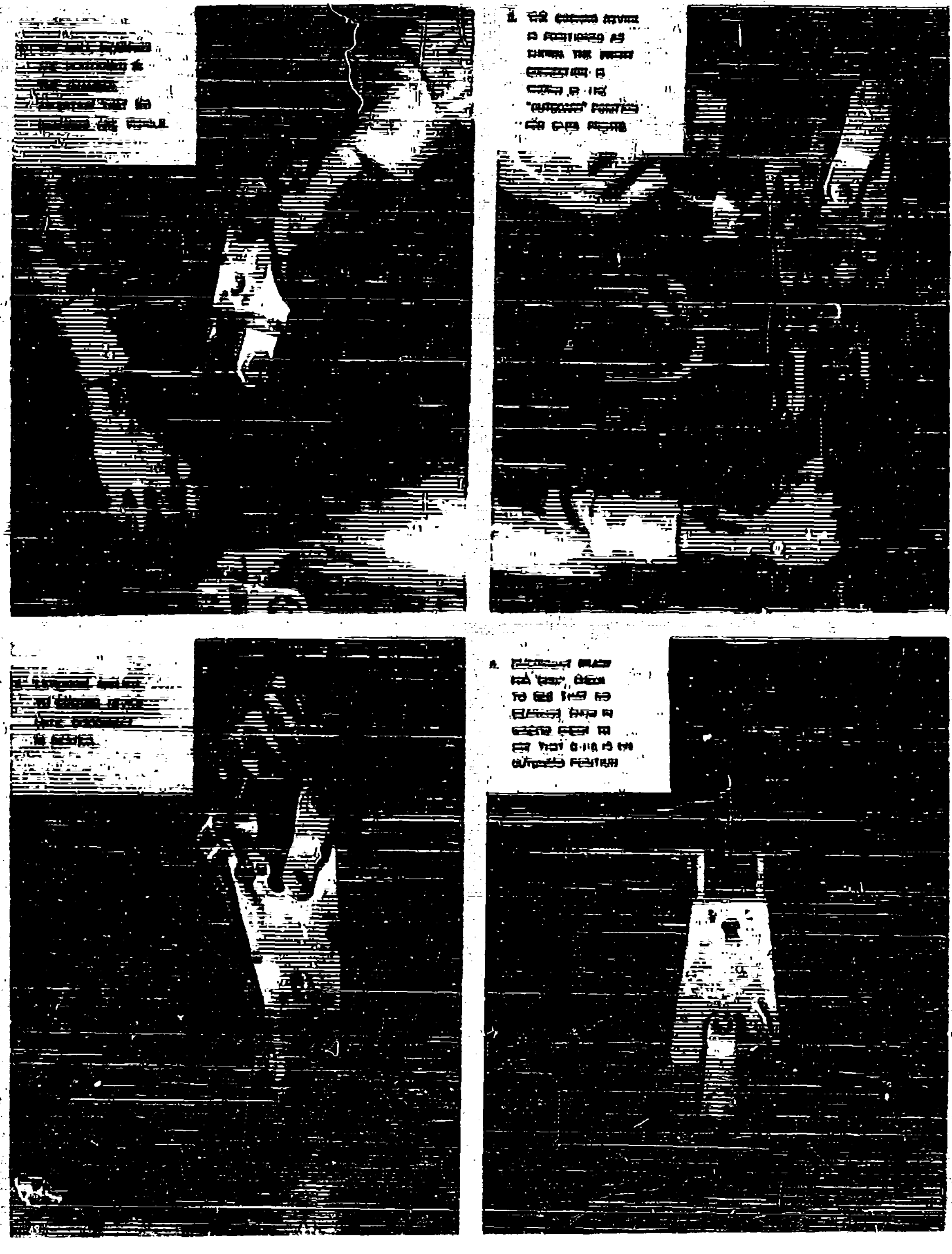


Figure 6-4-3. Parachute Canopy Ground Disconnect – Mechanical, 5,000 Pounds Capacity – Preparation for Aerial Delivery

CHAPTER VI

SECTION 5

GROUND SHOCK ABSORBING DEVICES

5.1 GENERAL.

Generally, missile or drone recovery and aerial delivery systems strive to achieve a rate of descent of 25 to 30 feet per second. However, there are advantages in using the fastest rate of descent at which a drop can be accomplished successfully. Increase in rate of descent will, of course, increase the surface impact shock force. Many systems are designed for the best possible compromise between the descent and the ground impact shock absorbing systems. In some cases, the resistance to damage of the dropped object at the desired or other acceptable rate of descent is sufficient to disregard an impact shock absorbing system.

5.2 METHODS.

There are many ways in which impact shock forces imparted upon the load can be reduced. They are all based on an increase in deceleration time between initial contact of the system with the surface and complete deceleration, and/or the distribution of the impact force over a greater load bearing area. Containers may utilize both principles. They may be padded to partially absorb impact forces and blocked to distribute the forces more evenly over the load than would otherwise be the case. The same principles apply to platforms. Crash frames or padding (Figure 6-5-1) may be used to absorb some of the force and thereby increase deceleration time, while blocking can distribute the impact forces more evenly. On heavy aerial delivery systems and on some drone recovery systems, ground shock absorption by means of air bags has proven to be a satisfactory method. In some cases, ground penetration spikes have been used on missiles to absorb ground impact forces.

5.2.1 AIR BAG DECELERATOR, AERIAL DELIVERY SYSTEM. The air bag decelerator is a collapsible, barrel-shaped rubber bag mounted at the bottom of the load platform which is to be lowered by parachute. In its stowed position, the air bag is collapsed. When the load platform falls free of the aircraft, and the platform doors or antitoppling devices extend, the air bag decelerators distend by gravity and inflate with air that passes through check valves located at the bottom of the air bag. A diaphragm covering an orifice at the top of the bag prevents the escape of air while falling. Figure 6-5-2 shows the air bag decelerators extended. At ground impact, the check valves close, the diaphragm bursts, and the air escapes through the orifice. The rate of platform deceleration is determined by the rate of air flow through the orifice.

5.2.1.1 Due to the rate of descent, the load possesses kinetic energy. This energy, $E_k = mv^2/2$, must be absorbed by the air bag decelerator. The air bag accomplishes this function by exerting a resisting force upon the bottom of the load over a vertical distance, which is somewhat less than the expanded height of the air bag. Theoretically, a load having a rate of descent of 30 feet per second can be decelerated to zero velocity in approxi-

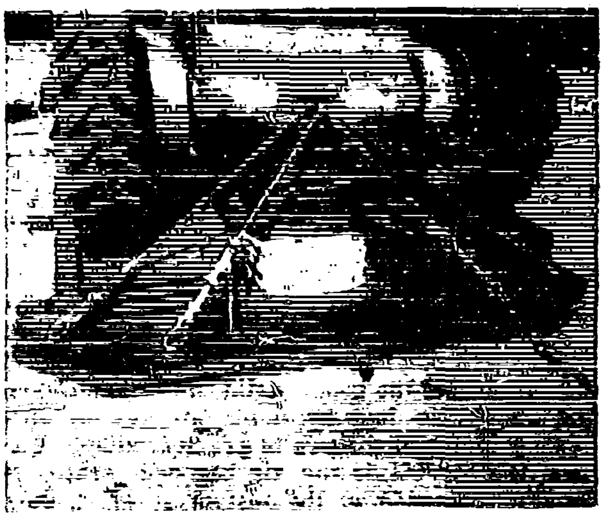


Figure 6-5-1. Utilization of Crash Frames and Padding Material for Heavy Aerial Delivery Systems

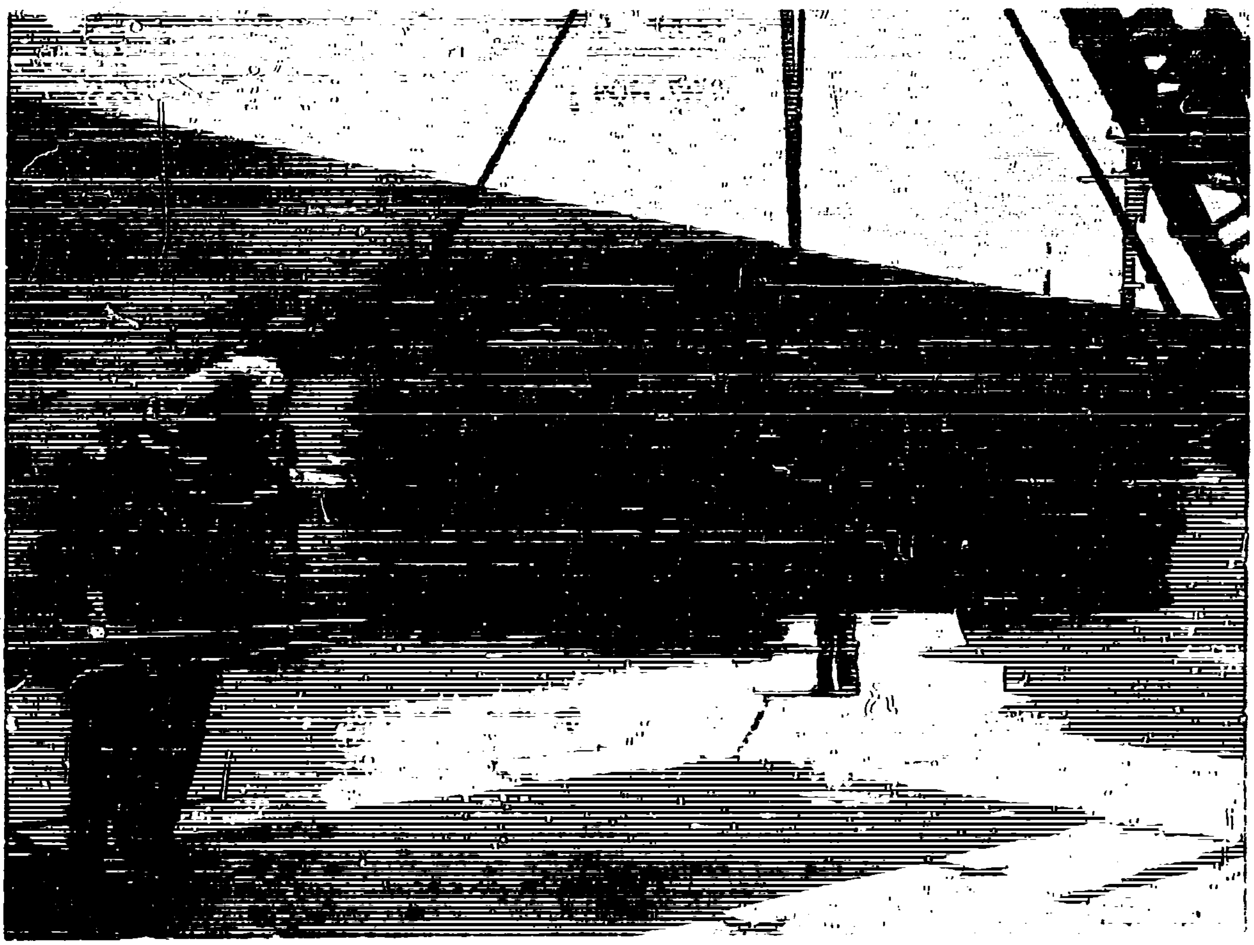


Figure 6-5-2. Air Bag Decelerators on Load Bearing Platform, Air Bags Extended

mately 17 inches distance with a uniform deceleration of 10 times the force of gravity. However, in practical application, this is impossible, since it means assuming that the deceleration begins at the instant of bag ground contact and is uniform during the entire deceleration period. During practical application, bag height is lost in developing air bag pressure to a working value, since it is developed simply by polytropic-volume compression of the air inside the bag. Furthermore, additional bag height is lost by using air venting as a means of limiting force of gravity values. Unless the air inside the air bag decelerator is rapidly released at the instant at which zero velocity is reached, the compressed air volume will act as a spring and will "bounce" the load upwards. This rapid air release, however, is impossible to achieve in practical application. Therefore, means must be explored to build up the air bag pressure as rapidly as possible to a predetermined value and then dissipate the energy by bleeding the air continually throughout the remaining compression cycle. This is achieved, within limits, by covering the orifice at the tope of the air bag with a diaphragm of a certain blowout pressure and diameter.

5.2.1.2 Two different air bag decelerator types are presently being used, one designed to decelerate a load of 1000 pounds and the other to decelerate a load of 2,500 pounds at values not exceeding ten (10) times the force of gravity when striking the ground at a rate of descent of up to thirty (30) feet per second. Figure 6-5-3 shows the effect of orifice diameter, diaphragm burst pressure, and weight per air bag upon air bag pressure for an air bag decelerator designed to decelerate a load of 2,500 pounds.

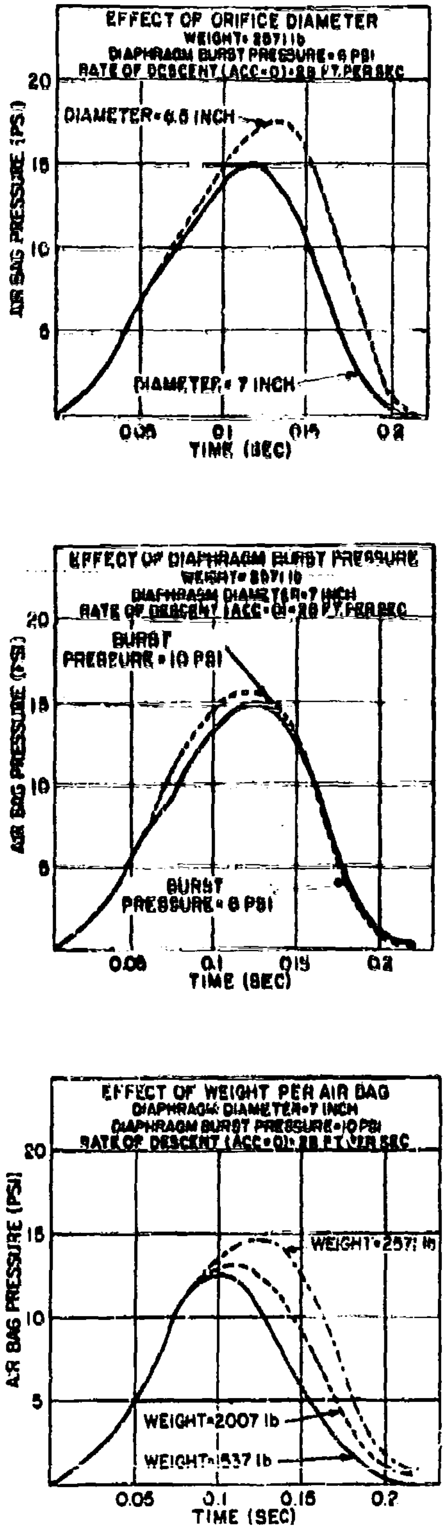


Figure 6-5-3. Effect of Orifice Diameter, Diaphragm Burst Pressure, and Weight per Air Bag upon Air Bag Pressure: Air Bag Capacity — 2,500 Pounds

5.2.2 AIR BAG DECELERATOR, MISSILE AND DRONE RECOVERY SYSTEM. Air bag decelerators for missile and drone recovery systems are designed essentially along the same basic principles as those used for aerial delivery systems. The shape of these air bag decelerators may be other than barrel shaped because of the missile or drone configurations. Generally, these air bags are prepressurized and filled with nitrogen gas or dry air. Prepressurization will increase air bag efficiency; however, it will also require gas storage containers or compressors. Air bag inflation is automatic and may be part of the recovery system sequence control.

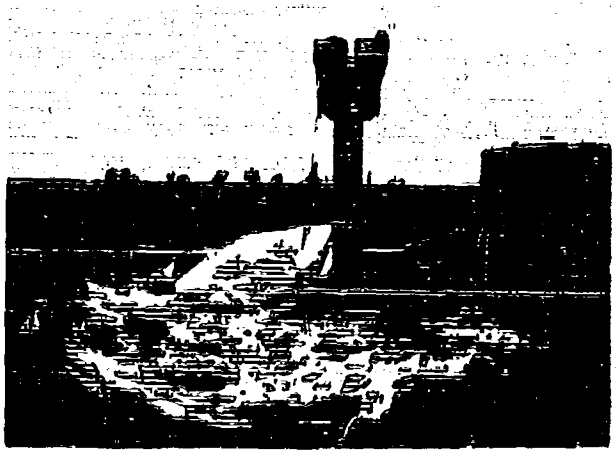


Figure 6-5-4. Shock Absorption by Ground Penetration Spike

5.2.3 GROUND PENETRATION SPIKE. Ground penetration spikes, rigidly attached to the nose of a missile, provide a good shock absorption system when used under proper conditions (Figure 6-5-4). The advantage of this method, compared with inflatable air bag decelerators, is that higher rates of load descent (for example, 50 to 60 feet per second) can be used. In fact, the greater rate of descent is needed, so that the vertical component of the force will enable the spike to penetrate the ground to a depth that will prevent the missile from falling over. This method of shock absorption is advantageous when the volume available in the missile does not permit the stowage of a larger parachute or air bag decelerators. The disadvantage of this method is that the actual effectiveness of the spike depends largely upon the hardness of the terrain on which impact occurs. Also, the missile structure must be designed to withstand forces of the magnitude and direction imposed by the spike.

CHAPTER VII

SUPPORTING EQUIPMENT

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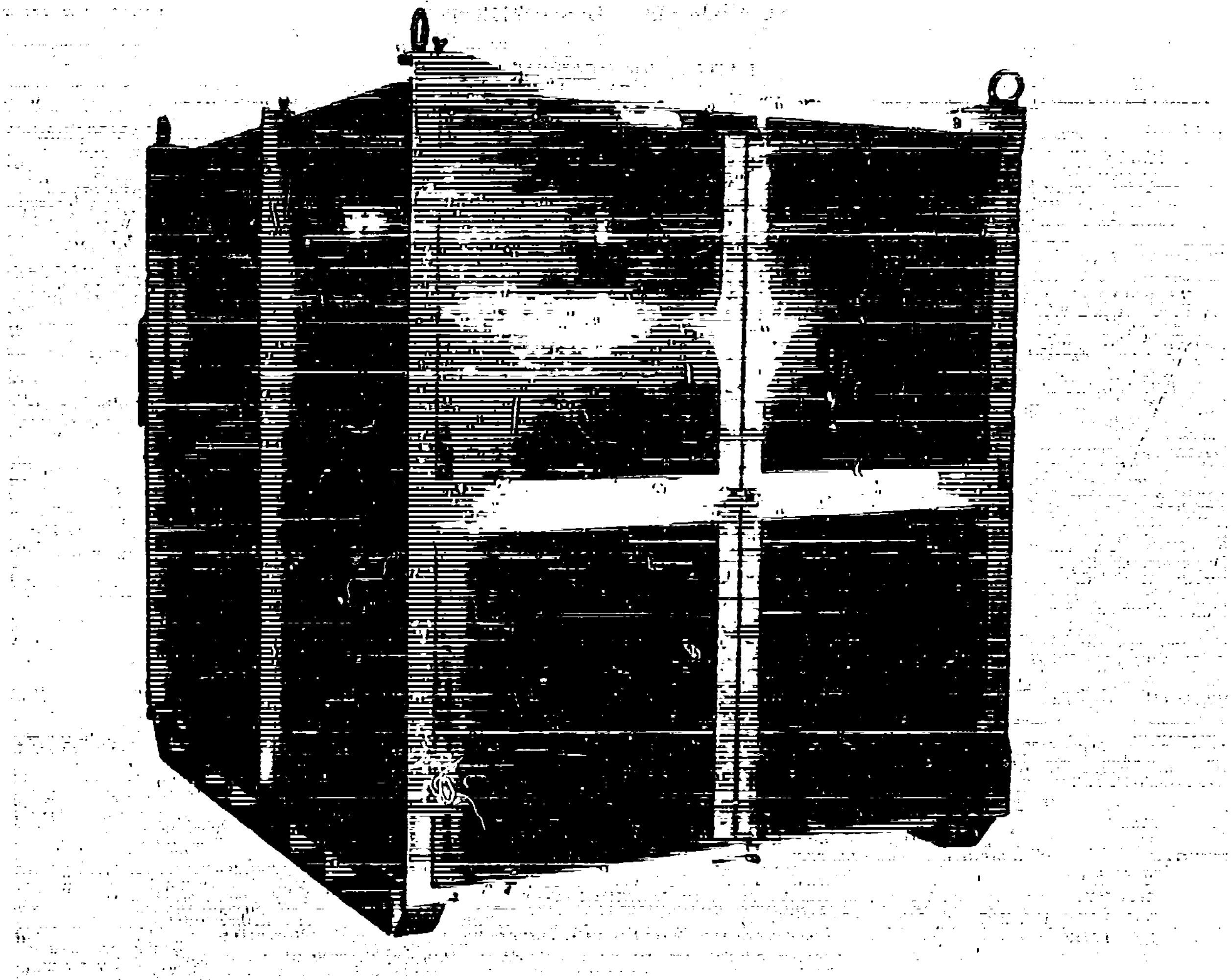

Frontispiece. Parachute Drying Cabinet, Portable

CHAPTER VII

SECTION 1

PARACHUTE DRYING TOWER

1.1 GENERAL.

Parachute drying towers are used to ventilate and dry parachute canopies, to provide a place to allow creases in the canopy to soften, and to permit shaking out dust, dirt, and the like picked up after use. Availability of a parachute drying tower is a requisite for the maintenance of personnel type parachutes.

1.2 DRYING TOWER REQUISITES.

A drying tower can be thought of as an over-sized room, sufficiently high for a canopy to hang freely, without touching the floor, when suspended from the apex. In order to draw the canopy to the ceiling, hooks and pulleys must be provided. Canopy suspension hooks are generally spaced approximately 3 feet apart, but this distance may be varied if the canopies generally hung in the facility require more room to hang clear of each other. Areas likely to come in contact with the canopy should be smooth and free from nails. Walls should be covered with polished hardboard or equivalent material. Warm, filtered, forced air should be provided, and dehumidification is desirable. The area should not be subject to exhaust, solvent, or acid fumes.

CHAPTER VII

SECTION 2

PARACHUTE DRYING CABINET

2.1 GENERAL.

Parachute drying cabinets are used for the accelerated drying of all types of parachutes. Drying cabinets were first developed as a result of a shortage of parachute drying tower facilities at bases where a large number of aircraft deceleration parachutes were in use, and also from a required frequency of parachute use. Because of their application, aircraft deceleration parachutes tend most to become wet and collect dust, tar, and other contaminants. These parachutes should not be hung in a drying tower adjacent to personnel parachutes. The drying cabinet is now used primarily for rapid drying of parachutes for aircraft deceleration applications. Its use, however, does not render the drying tower obsolete.

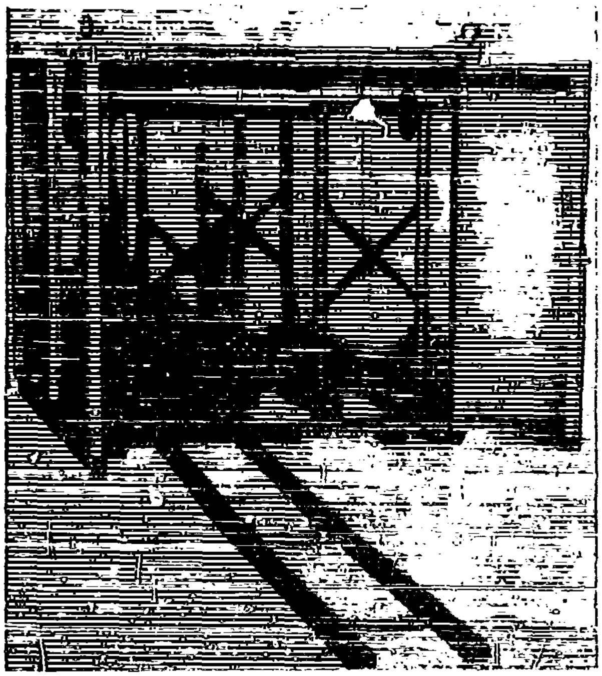

Figure 7-2-1. Parachute Drying Cabinet, Portable — Interior View

2.2 CABINET.

The drying cabinet (Figure 7-2-1) is an all-metal cabinet capable of being transported in the air. It measures 6 feet by 6 feet by 8 feet in the erected state. The cabinet is designed to allow assembly or disassembly in the field by two men utilizing standard tools. The heating source for the cabinet consists of a Herman Nelson type BT-400 or equivalent heater, which is capable of delivering 400,000 BTUs per hour at an ambient temperature of -65°F. The heat is transferred from the heater to the cabinet through a 12-inch-diameter duct, 15 feet long. Temperature within the cabinet is automatically maintained at a level of 200°F. The inside of the cabinet is smooth and without any protrusions. Dual racks, provided with easily removable and replaceable caster wheels, hold the canopy in place during the drying cycle. The cabinet can dry two thoroughly wet 44-feet-diameter FIST ribbon type canopies or their equivalent in three hours.

CHAPTER VII

SECTION 3

PARACHUTE PACKING AND INSPECTION FACILITIES

3.1 GENERAL.

The requirements for a parachute packing and inspection building are relatively simple. The building itself must be sufficiently large to permit free movement around the packing and inspection tables. Lighting in the vicinity of the working areas, both daylight and artificial, must be very good. Washing facilities for canopies are desirable. A parachute drying tower must be a part of the building, or be attached to it. Special furnishings include bins, issuing counters, and storage facilities.

3.2 PARACHUTE PACKING TABLES.

Parachute packing tables may be of local manufacture. They should stand about 30 inches high and should be of sufficient length to accommodate the full length of the canopy and the suspension lines extended. A width of 3 feet is sufficient for personnel parachutes. Six-foot width should be used for cargo parachute canopies larger than 28 feet in diameter. The top of the table should be of polished hardboard or similar material. The top and other areas likely to come in contact with material should be free of anything that might snag or pull the material. The table should be equipped with a suitable device to place the suspension lines and canopy under an evenly distributed tension in preparation for folding the parachute.

3.3 PARACHUTE INSPECTION TABLES.

Parachute inspection tables may be manufactured locally. They may be ironing-board shaped, approximately 18 foot long, 3 feet high, and tapering in width from 3 to 2 feet. A light is inset in the center of the table and extends the full length. The face of the light is smooth plate glass and is set flush with the table surface. During inspection, the light passes through the canopy, revealing damage of yarn, appearance of edges in radial and diagonal seams, suspension lines in channels, and threading midway between surfaces of the material. A hand-held ultraviolet light is used to detect stains in the material. All portions of the table that might come in contact with material must be free of anything that could snag or pull the material.

3.4 BINS.

Bins should be located convenient to the packing and inspection tables. They must be able to accommodate unpacked parachutes. The bin surfaces must be smooth, and must be free from cracks, nails, or other objects that might snag or pull the material.

3.5 STORAGE FACILITIES.

Storage facilities requirements vary with the contemplated length of time of storage, the climatic conditions, and the type of building construction. Some fabrics are particularly susceptible to mildew damage in regions having a warm, humid climate. Parachutes should be dried thoroughly before packing, and then stored in a dry place. They should not be stored in direct contact with concrete floors. Wooden racks, protected from the sun's rays, are desirable. Cleanliness is important; grease, oil, or other contaminants must not be kept in, or used on the surfaces of, the storage area.

3.6 PARACHUTE PACKING TOOLS.

The following tools are generally considered necessary for packing and inspection: (See figure 7-3-1.)

a. Line Separator: This is a small, slotted stand used to hold the suspension lines in their respective group for packing.
b. Shot Bags: These are cloth sacks, approximately 18 inches by 4 inches, filled with about 5 pounds of shot They are placed on material or lines to hold them in temporary placement. They are used particularly for holding the folded half of a canopy while the other half is being folded.
c. Folding Tool: This is used to automatically make and fold the correct width or length of canopy so that it will properly fit the pack.

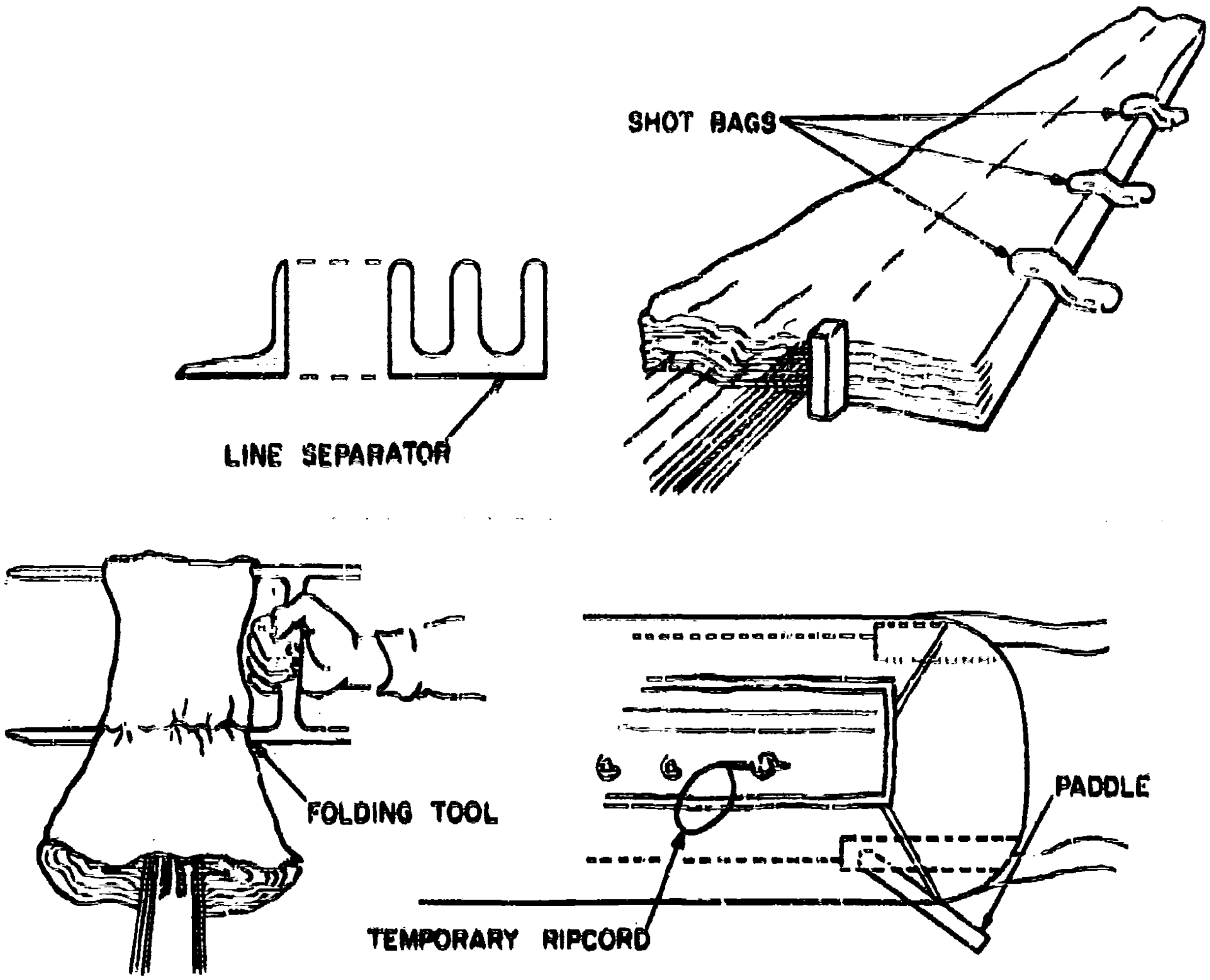

Figure 7-3-1. Parachute Packing Tools

d. Ripcord, Temporary: A temporary ripcord consists of a short ripcord with pins. In use, it is inserted into the locking cones or loops of the pack to hold the side flaps in place so that the end flaps may be placed in position to insert the permanent ripcord.
e. Press, Seal: This is a hand operated device used to secure the seal applied by the packer or inspector to seal the packed parachute against tampering.
f. Assortment of Small Tools: Long-nosed pliers; knife; six-inch shears; ten-inch shears; needles — sharp, blunt, and curved; hammer; packing paddle; six-inch steel tape; hook, palm.

3.7 SEWING MACHINES.

Machines suitable for parachute repair and production are covered in Federal Specification 00-S-256, "Sewing Machines, Industrial Type for Textiles," and Federal Specification GG-S-225. Many attachment innovations help in parachute production. Needle coolers and thread lubricants are used to overcome needle heat.

CHAPTER VIII

TEST EQUIPMENT AND TEST METHODS

In the development and study of parachutes, it has become increasingly evident that accurate and reliable testing equipment and methods are a necessity. Instrumentation and testing have been prime factors in determining the design characteristics of parachutes for a variety of applications. The use of proper test equipment and testing methods makes possible fast development and evaluation, fast correction of design deficiencies, and the most expeditious development to the stage of actual application. In the following sections, experimental test vehicles, specialized parachute performance data recording systems, and experimental parachute test methods are described. This description is given to present a comprehensive picture of available equipment and facilities, specific capabilities, limitations, performance characteristics of equipment, methods of testing experimental parachutes and parachute systems, and methods of obtaining desired performance characteristics.

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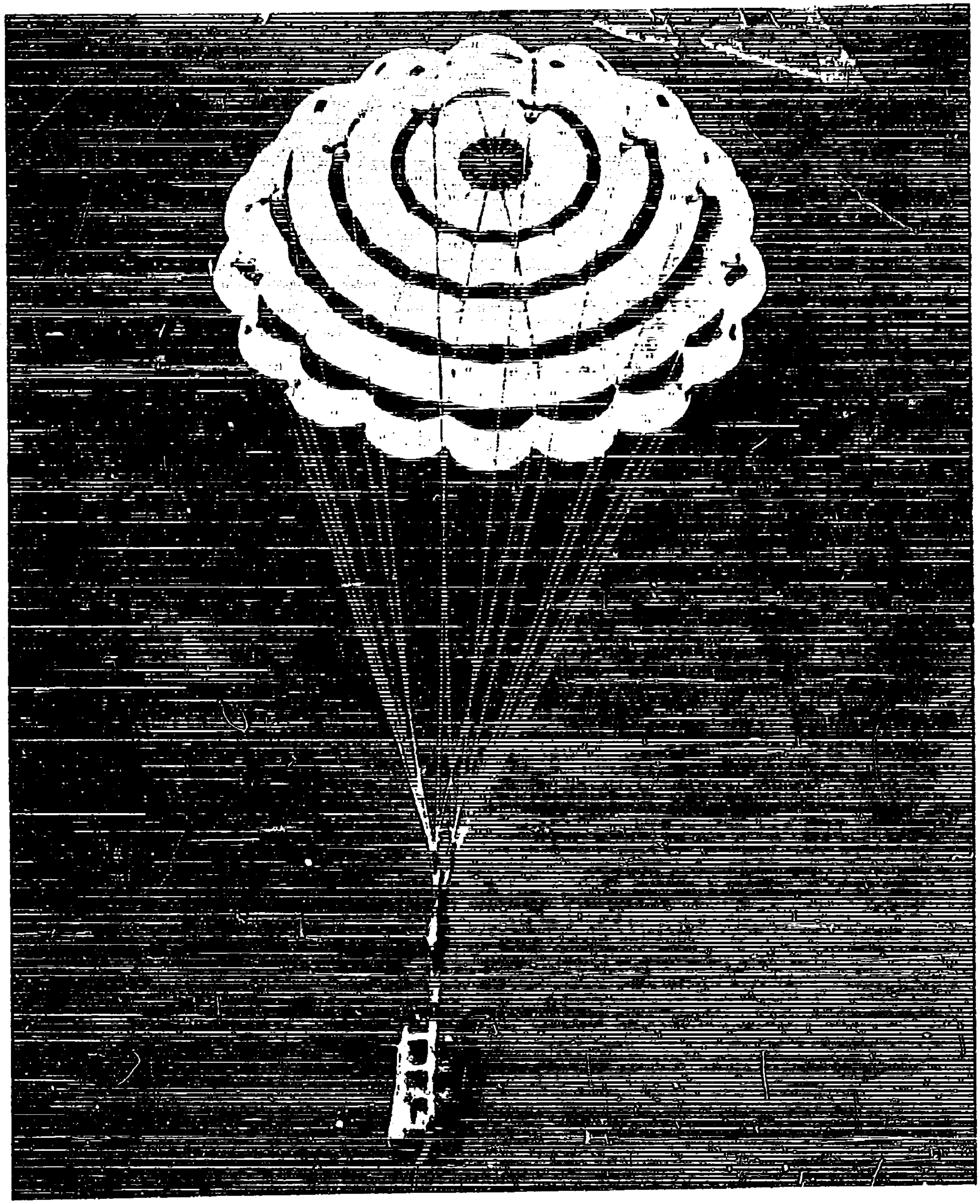


Frontispiece. Drop Test -- Ring Slot Parachute -- Self-Recording Tensiometer Is Between Load and Canopy

CHAPTER VIII

SECTION 1

TEST EQUIPMENT

1.1 DROP TEST VEHICLES.

A number of drop test vehicles have been developed and are being used for the purpose of testing experimental parachutes and parachute systems for a particular application. Figures 8-1-1 through 8-1-6 show the types of drop test vehicles available and their capacities and limitations.

1.2 PARACHUTE PERFORMANCE DATA RECORDING INSTRUMENTS.

1.2.1 GENERAL. The program of applied research for the field of parachute aerodynamics necessitates the development of specialized instruments and instrument systems. Since the design of new parachutes and the improvement of existing parachutes is largely dependent upon the knowledge of individual performance characteristics of different types of chutes designed, the availability of accurate and reliable data recording systems and instruments cannot be overemphasized. For a majority of parachute tests, particularly during the experimental stage, only the knowledge of exploratory information on parachutes or systems is required. Therefore, for this test phase, an instrument should be used which will be economical in use but capable of rendering results with satisfactory accuracy. The self-recording instruments are placed in this category. If a parachute system has proven its reliability during the experimental testing phase and more accurate data is desired, or if during any one test various different performance data are to be recorded versus a common time base, either a telemetering system or a magnetic tape recording system is used, depending upon economy of test and accuracy of data desired.

During the initial stages of parachute development and for applied parachute research, static test facilities, such as wind tunnels, are used to a large extent. Various types of instrument systems are available to measure and record required parachute phenomena with a high degree of accuracy. The following listing is a summation of sensing elements, recording systems, and data reduction systems available and used in the field of parachute research and development. No attempt is made to furnish a complete listing of all instruments that may be used. Only those instruments are mentioned, and their performance characteristics listed, that have been developed especially for applications in the field of parachutes and/or have proven their suitability during a large number of parachute test applications.

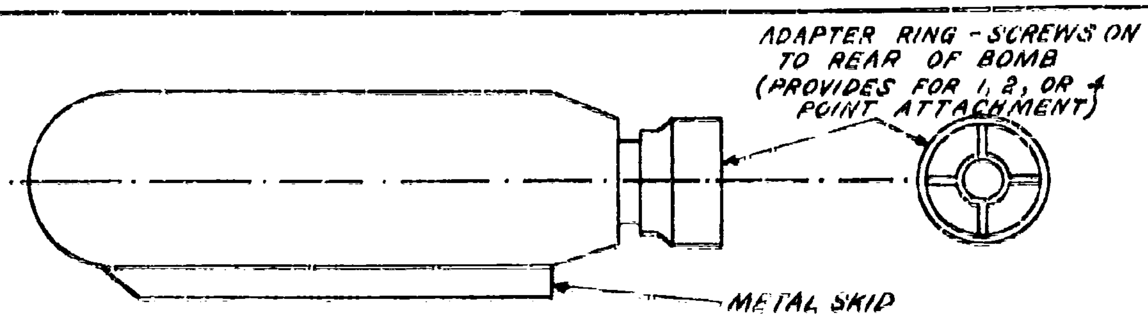
1.2.2 SENSING ELEMENTS.

1.2.2.1 Force Sensing Elements.

1.2.2.1.1 Variable Resistance (Strain Gage) Type. (See Figure 8-1-7.) Various types of variable resistance type tensiometer links have been developed and are commercially available in capacity ranges from about one to 150,000 pounds. The dimensions, weight, and volume are dependent upon the size of the link. The same is true for natural frequency. Type numbers may be found in manufacturers' catalogs. These variable resistance type tensiometers are used in connection with oscillographs, tape recording systems, telemetering systems, and direct reading instruments. They are used for all applications where knowledge of force values in any part of the parachute or of the parachute system is desired.

1.2.2.1.2 Variable Reluctance Type. (See figure 8-1-8.) The variable reluctance type of sensing elements are being produced commercially by a number of manufacturers. They are generally used in telemetering systems. Link sizes capable of measuring forces from 0 to 16,000 pounds compression, or from 0 to 16,000 lb. tension are available.

The element itself is relatively expensive compared to other types of force sensing elements. Its application is limited to use on risers, suspension lines, harnesses, and other applications where bulkiness is not of importance. A disadvantage of this type unit is its sensitivity to temperature change.



TYPES	1	2	3	4	5
WEIGHT RANGE (LB.)	300 1250	1000 2500	2000 5000	4000 10000	7000 16000
BASIC STRUCTURE	GP 500	GP 1000	GP 2000	LC 4000	T-10
MAXIMUM G'S	15	10	8	5	5
MAXIMUM SPEED (KNOTS)	200	200	200	200	200
VOLUME OF PARACHUTE COMPARTMENT	PARACHUTE IS EXTERNALLY MOUNTED				
USUAL CARRYING AIRCRAFT	CARGO				
DEPLOYMENT METHOD	STATIC LINE				
UNDERCARRIAGE FOR CARGO AIRCRAFT	ATTACHED SKID				WOOD CRADLE
INSTRUMENTATION	SELF-RECORDING TENSIOMETER SELF-RECORDING ACCELEROMETER DROPLINE - (RATE OF DESCENT) SOME APPLICATIONS - TELEMETERING				

ADVANTAGES:

1. COMPLETE COVERAGE OF WEIGHT RANGE.
2. BOMB IS NEARLY INDESTRUCTIBLE.
3. SIMPLICITY.
4. EASY HANDLING.
5. STANDARD VEHICLE FOR COMPARATIVE ANALYSIS.
6. LOW COST, CASING IS STANDARD ITEM.

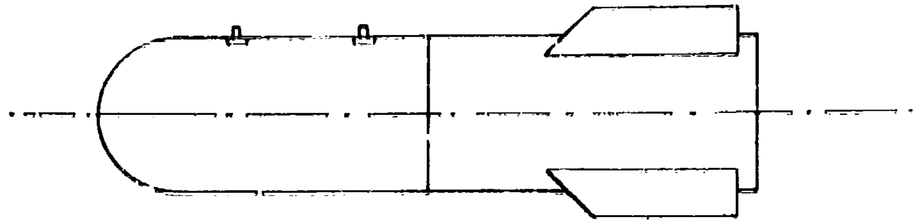
GENERAL

1. ALL TYPES OF PARACHUTES, WITH THE EXCEPTION OF PERSONNEL, MAY BE TESTED WITH THESE VEHICLES.
2. WHEN TYPE - 5 (T-10) IS USED IT IS NECESSARY TO USE AN EXTRACTION PARACHUTE SIMILAR TO THAT USED FOR HEAVY CARGO DELIVERY.
3. TYPE - 4 (4,000-LB. LIGHT CASING) AND TYPE - 5 (T-10) MAY BE USED FOR CLUSTERS.
4. THE PARACHUTE BAG MUST BE TIED EXTERNALLY TO THE BOMB. THE BOMB HAS RINGS WELDED TO THE OUTSIDE FOR ATTACHMENT.

DISADVANTAGES:

1. MAXIMUM SPEED AND ALTITUDE CAPABILITIES OF AIRCRAFT MAY PRECLUDE USE ON CERTAIN DESIRED TESTS.
2. PARACHUTE BAG IS NOT PROTECTED FROM AIRSTREAM.
3. ONLY CERTAIN AIRCRAFT CAN BE USED.
4. (AT PRESENT) TELEMETERING IS HELD TO ONE CHANNEL.
5. (AT PRESENT) INSTRUMENTATION MUST BE KEPT EXTERNAL AND IS SUBJECT TO DAMAGE.
6. VEHICLE IS NOT STABLE. IT HAS A TENDENCY TO TUMBLE.

Figure 8-1-1. Drop Test Equipment -- Disposable Load -- Weight Bomb



TYPES	1	2	3	4	5	6	7	8	9
WEIGHT RANGE (LB)	300 1250	1000 2500	2000 5000	4000 10000	7000 16000	15000 40000	15000 40000	7000 16000	15000 40000
BASIC STRUCTURE	GP 500	GP 1000	GP 2000	LC 4000	T-10	T-12	NEW	T-10	NEW
MAXIMUM G'S	20	15	10	7	5	4	4	5	4
MAXIMUM SPEED (KNOTS)	300 STATIC LINE 450 TIME DELAY	300 STATIC LINE 450 TIME DELAY	300 STATIC LINE 450 TIME DELAY	300 STATIC LINE 450 TIME DELAY	200	200	200	200	200
VOLUME OF PARACHUTE COMPARTMENT (CU. FT.)	3.85	9.52	17.75	55.50	APPROX. 60	APPROX. 120	APPROX. 120	APPROX. 60	APPROX. 120
USUAL CARRYING AIRCRAFT	FIGHTER OR LIGHT BOMBER			BOMBER					
DEPLOYMENT METHOD	STATIC LINE OR T-8 EJECTION GUN				STATIC LINE				
RELEASE	BOMB SHACKLE, PREMATURE RELEASE								
INSTRUMENTATION	SELF-RECORDING TENSIOMETER SELF-RECORDING ACCELEROMETER TELEMETERING (ONE CHANNEL) CAMERAS								

ADVANTAGES:

1. HIGHER SPEED THAN WEIGHT BOMBS.
2. RESISTANT TO DAMAGE; ONLY TAIL SUFFERS.
3. SIMPLICITY.
4. EASY HANDLING.
5. LOW COST; FORE PART IS STANDARD ITEM.
6. CAN BE FABRICATED LOCALLY.
7. STABLE TRAJECTORY IN FREE FALL.

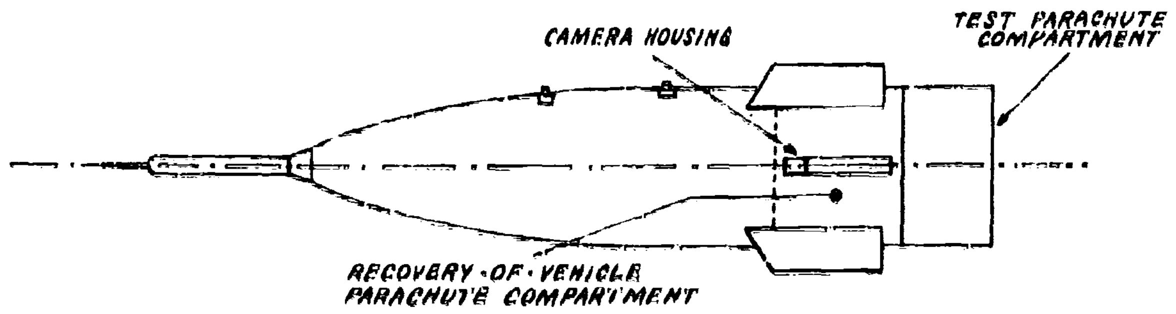
DISADVANTAGES:

1. SPECIAL PARACHUTE BAGS MUST BE MADE TO FIT VEHICLE.
2. BAG MAY NOT EXACTLY DUPLICATE THAT FOR FINAL APPLICATION.
3. LIMITED SPEED.
4. CAMERAS MUST BE EXTERNALLY MOUNTED.

GENERAL

TYPES 6 THROUGH 9 ARE UNDER DEVELOPMENT.

Figure 8-1-2. Drop Test Equipment -- Disposable Load -- Cylindrical Test Vehicle



TYPES	1	2	3	4
WEIGHT RANGE (LB.)	800 2000	2000 6000	800 2000	2000 6000
MAXIMUM G'S	20 1ST STAGE 20 2ND STAGE	10 1ST STAGE 17 2ND STAGE	—	—
MAXIMUM SPEED	MACH 1	MACH 1	MACH 1.5	MACH 1.5
VOLUME OF PARACHUTE COMPARTMENT (cu FT)	1.0 1ST STAGE 4.5 2ND STAGE	2.5 1ST STAGE 7.0 2ND STAGE	—	—
USUAL CARRYING AIRCRAFT	FIGHTER OR HIGH SPEED BOMBER			
DEPLOYMENT METHOD	INTERNAL PROGRAMMING TIMER TO INITIATE SUCH FUNCTIONS AS: 1. INITIATION OF DEPLOYMENT OF TEST PARACHUTE AFTER TIMED FREE FALL. 2. RELEASE OF ENTIRE COMPARTMENT HOUSING OF TEST PARACHUTE FROM VEHICLE PERMITTING VEHICLE TO DESCEND BY OWN PARACHUTE SYSTEM.			
INSTRUMENTATION	COMPLETELY TELEMETERED TO INCLUDE FORCE RECORDINGS OF TEST PARACHUTE; FORCE RECORDINGS OF MAIN PARACHUTE(S); ALTITUDE; AIRSPEED; AND PROGRAMMING CHANNEL TO RECORD EACH SEQUENCE AND TIME TAKEN PLACE. SELF-RECORDING TENSIOMETER, SELF-RECORDING ACCELEROMETER.			

ADVANTAGES:

1. HIGH SPEED MAY BE ATTAINED IN FREE FALL.
2. COMPLETE TEST INFORMATION MAY BE OBTAINED BY TELEMETERING.
3. PARACHUTE SYSTEM CARRIED INTERNALLY.
4. VEHICLE MAY BE RECOVERED BY OWN SYSTEM REGARDLESS OF OPERATION OF TEST PARACHUTE.
5. VERY STABLE TRAJECTORY.
6. INSTRUMENTATION IS CARRIED INTERNALLY.
7. CAMERA POD ATTACHED (PERMANENTLY) TO VEHICLE.

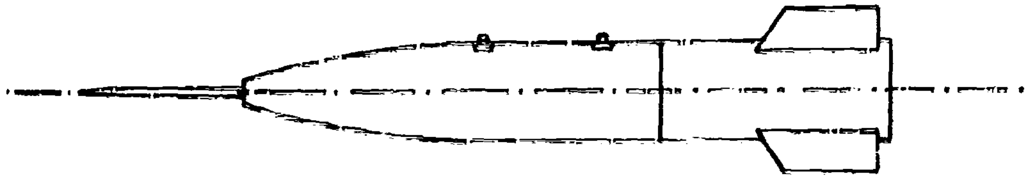
GENERAL

1. TEST PARACHUTE COMPARTMENT HOLDS TEST PARACHUTES USED FOR DECELERATION STAGE CHUTES FOR MISSILES OR FOR HIGH SPEED TARGETS AND DRONES.
2. MAXIMUM SPEED IS REACHED BY FREE FALL OR HIGH SPEED RELEASE.
3. RECOVERY CHUTE USED FOR VEHICLE MAY SERVE AS A PARTIAL BASIS FOR 2-STAGE TEST.

DISADVANTAGES:

1. HIGH INITIAL COST.
2. CANNOT BE FABRICATED LOCALLY.
3. COMPLEX SYSTEM, REQUIRES SKILLED TECHNICAL MAINTENANCE.
4. TEST PARACHUTE MUST BE PACKED IN BAG TAILORED FOR TEST PARACHUTE COMPARTMENT. (MAY NOT DUPLICATE FINAL APPLICATION.)
5. GENERALLY REQUIRES HIGH-SPEED, HIGH-ALTITUDE AIRCRAFT FOR TYPE OF TEST IN WHICH IT IS EMPLOYED.

Figure 8-1-3. Drop Test Equipment -- Disposable Load -- Transonic Test Vehicle



TYPES	5	6	7
WEIGHT RANGE (LB.)	800 2000	235 500	500 2000
MAXIMUM G'S	25	APPROX. 10	10 1ST STAGE 15 2ND STAGE
VOLUME OF PARACHUTE COMPARTMENT	2.3	—	—
USUAL CARRYING AIRCRAFT	FIGHTER OR HIGH SPEED BOMBER		
DEPLOYMENT METHOD	T-2 EJECTION GUN	STATIC LINE OR QUILTER TIMER	INTERNAL PROGRAMMING TIMER
MAXIMUM SPEED	MACH 1+	400 K	600 K
BASIC STRUCTURE	MARK 83 EX-10	GP 500	GP 1000
INSTRUMENTATION	COMPLETELY TELEMETERED TO INCLUDE FORCE RECORDINGS OF TEST PARACHUTE; FORCE RECORDINGS OF MAIN PARACHUTE(S); ALTITUDE; AIRSPEED; AND PROGRAMMING CHANNEL TO RECORD EACH SEQUENCE AND TIME TAKEN PLACE. SELF-RECORDING TENSIOMETER, SELF-RECORDING ACCELEROMETER		

ADVANTAGES:

1. HIGH SPEED MAY BE OBTAINED AT HIGH ALTITUDE WITHOUT NECESSITY OF LONG FREE FALL.
2. COMPLETE TEST INFORMATION MAY BE OBTAINED BY TELEMETERING.
3. PARACHUTE SYSTEM CARRIED INTERNALLY.
4. VEHICLE MAY BE RECOVERED BY OWN SYSTEM REGARDLESS OF OPERATION OF TEST PARACHUTE.
5. VERY STABLE TRAJECTORY.
6. INSTRUMENTATION IS CARRIED INTERNALLY.

DISADVANTAGES:

1. HIGH INITIAL COST.
2. CANNOT BE FABRICATED LOCALLY.
3. COMPLEX SYSTEM, REQUIRES SKILLED TECHNICAL MAINTENANCE.
4. TEST PARACHUTE MUST BE PACKED IN BAG TAILORED FOR TEST PARACHUTE COMPARTMENT. (MAY NOT DUPLICATE FINAL APPLICATION.)
5. HIGH OPERATING COST.

GENERAL

1. TYPES 6 AND 7 ARE NOW OBSOLETE.
2. OTHER VEHICLES ARE UNDER DEVELOPMENT FOR SUPERSONIC TESTS. WEIGHT RANGE IS 800 TO 2,000 LB. AND 2,000 TO 6,000 LB.

Figure 8-1-4. Drop Test Equipment -- Disposable Load -- Supersonic Test Vehicle

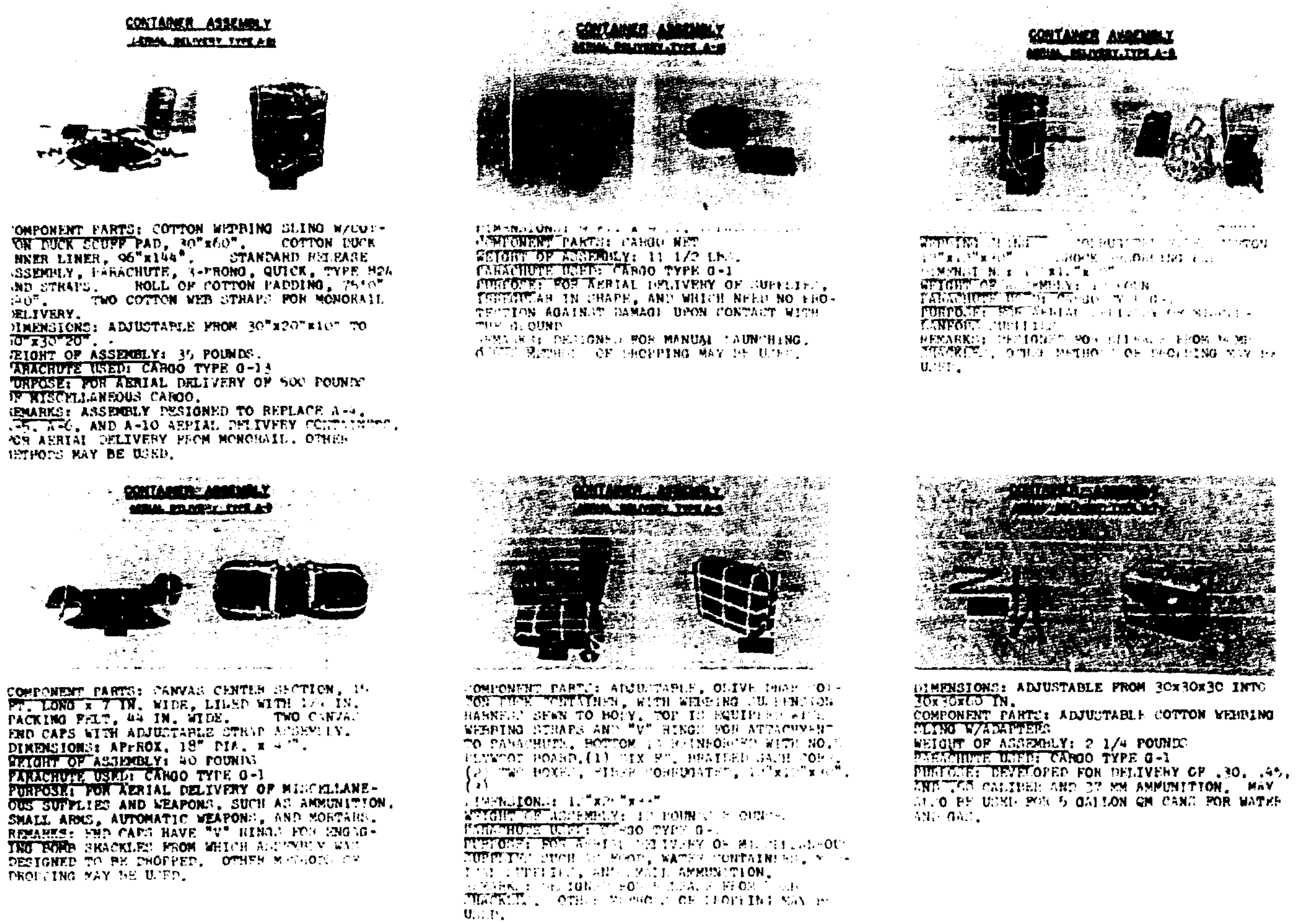


Figure 8-1-5. Containers

1.2.2.2 Accelerometers.

1.2.2.2.1 Variable Resistance (Strain Gage) Type. (See Figure 8-1-9.) Almost all types of acceleration pickups consist of a mass and spring housed in a suitable case and damped. When gravitational forces are imposed upon the sensing element, relative movement between the mass and case is produced, and a transducing device of some sort, which is incorporated in the instrument, is caused to produce an electrical signal proportional to the displacement or velocity of the mass with respect to the case. The mass and spring system in these sensing elements has one degree of freedom, because the mass is constrained to move in a straight line inside the case. A variety of accelerometer type sensing elements have been developed. Most commonly used in the field of parachute instrumentation is the variable resistance type accelerometer. These sensing elements may be obtained commercially in a wide variety of ranges and in various sizes, weights, and volumes, depending upon these ranges. The range generally used in the field of parachutes is between ± 2 g and ± 200 g. The natural frequency will depend upon the particular range and may be obtained from manufacturers' catalogs. These variable resistance type accelerometers are used in connection with oscillographs, tape recording systems, telemetering systems, and direct reading instruments for the measurement of gravitational forces. They are often used to measure ground impact shock of platforms and other cargo loads.

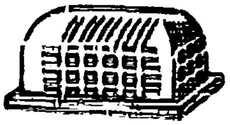
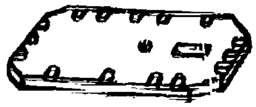
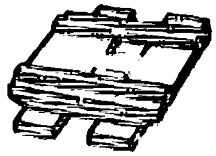
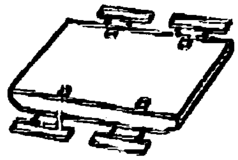
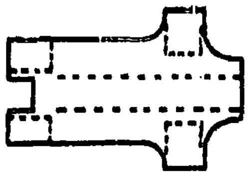
ITEM		GENERAL SHAPE	DESCRIPTION
CONTAINER	A-22		CANVAS CONTAINER, WEBBING BELTS, 2,200 LB. MAXIMUM LOAD, MAY BE DROPPED AT SPEEDS UP TO 200 KNOTS FROM CARGO-TYPE AIRCRAFT. INSTRUMENTATION: SELF-RECORDING TENSIOMETER OR ACCELEROMETER
PLATFORM	J-1		METAL PLATFORM FOR LOADS OF 3,000 TO 10,000 LB., MAY BE DROPPED AT SPEEDS UP TO 130 KNOTS FROM CARGO-TYPE AIRCRAFT. CAN BE FULLY INSTRUMENTED
PLATFORM	BROOKS AND PERKINS		STRESSED TYPE METAL PLATFORM NOW UNDERGOING EVALUATION, CAN BE USED FOR LOADS OF 5,600 TO 10,000 LB., DROP SPEED 130 KNOTS FROM CARGO-TYPE AIRCRAFT, HAS ANTI-TOPPLING DEVICE AND PROVISION FOR AIR BAGS. CAN BE FULLY INSTRUMENTED
PLATFORM	LOCKHEED { 16' 24'		STRESSED TYPE, CENTER RAIL RESTRAINT PLATFORM. NOW UNDERGOING EVALUATION. CAN BE USED FOR LOADS OF 5,000 TO 25,000 LB., DROP SPEED 130 KNOTS FROM CARGO-TYPE AIRCRAFT. HAS ANTI-TOPPLING DEVICE AND PROVISION FOR AIRBAGS. CAN BE FULLY INSTRUMENTED
TORSO DUMMY			RUBBER DUMMY USED FOR TESTING PERSONNEL PARACHUTES AND SYSTEMS; CENTER, ARM, AND LEG TUBES PROVIDE SPACE FOR INSTRUMENTATION, WEIGHT RANGE 170 TO 320 LB., PARACHUTE IS MOUNTED EXTERNALLY, FULL INSTRUMENTATION POSSIBLE.
SIMPLE AND COMPLEX ARTICULATED DUMMIES			ARTICULATED DUMMIES WITH ARM AND LEG MOVEMENT COMPARABLE TO HUMANS, PLATFORM IN BODY HOLDS INTERNAL INSTRUMENTATION, WEIGHT APPROXIMATELY 300 LB., CAN BE DROPPED OR EJECTED BY CARGO-BOMBER-OR FIGHTER-TYPE AIRCRAFT. PARTICULARLY DESIGNED FOR TEST OF PERSONNEL PARACHUTE SYSTEMS TO DETERMINE POSSIBILITY OF LIMB FOULING OR INTERFERENCE OF SYSTEM. ALSO USED FOR EJECTION SEAT TESTS TO DETERMINE TUMBLING AND OTHER ACTIONS.
CONTAINERS, PLATFORMS, DUMMIES			

Figure 8-1-6. Containers, Platforms, Dummies

Figure 8-1-7. Variable Resistance Type Force Sensing Elements

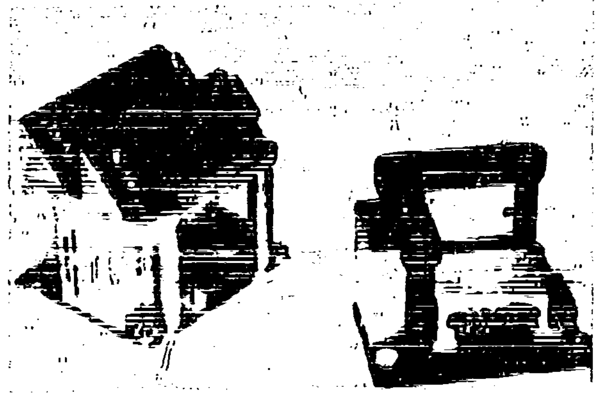


Figure 8-1-9. Variable Resistance Type Accelerometer

1.2.2.2.2 Variable Reluctance Type. (See Figure 8-1-10.) Variable reluctance type accelerometers are commercially available. For parachute systems tests, they are used in connection with telemetering systems. They respond to acceleration changes parallel to one axis only. Various ranges are available.

A disadvantage of this type sensing element is the necessity of maintaining uniform temperature for accuracy.

1.2.2.3 Pressure Transducers.

1.2.2.3.1 Variable Resistance (Strain Gage) Type. (See Figure 8-1-11.) For the measurement of velocity, altitude, rate of descent, and other differential or absolute pressures, pressure transducers are used. Again a wide variety of ranges are commercially available. In the field of parachutes, pressure transducers to measure differential pressure in the range of 0.1 to 30 psi and pressure transducers to measure absolute pressure in a range of between 0.1 and 20 psi are used. Dimensions, weight, and volume vary with the range of the transducer, as does natural frequency. Type numbers may be obtained from manufacturers' catalogs. These variable resistance type transducers are used in connection with oscillographs, tape recording systems, telemetering systems, and direct reading instruments for the measurement of differential and absolute pressure.

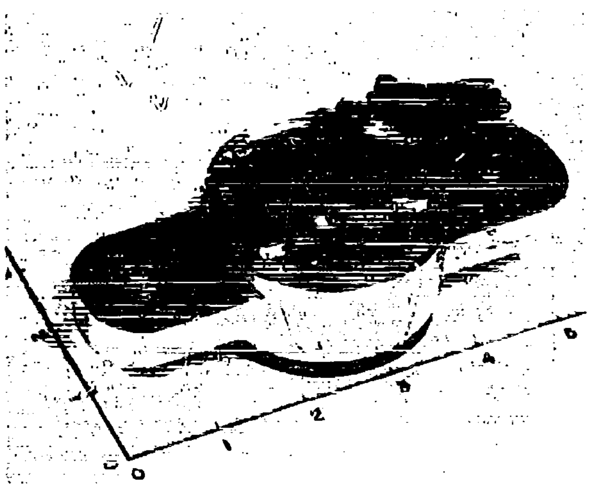


Figure 8-1-8. Variable Reluctance Type Force Sensing Elements

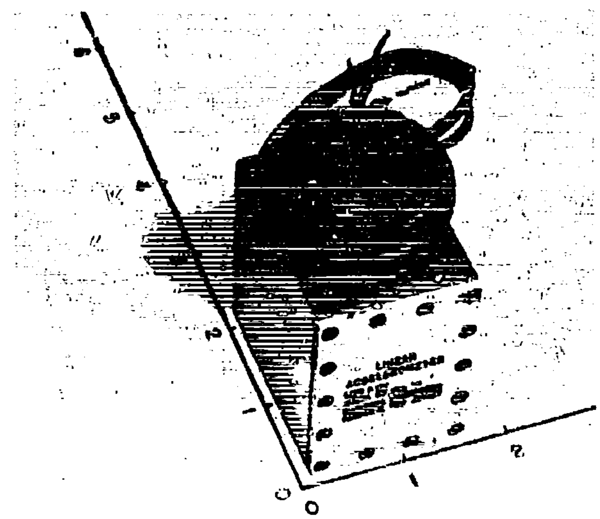


Figure 8-1-10. Variable Reluctance Type Accelerometer

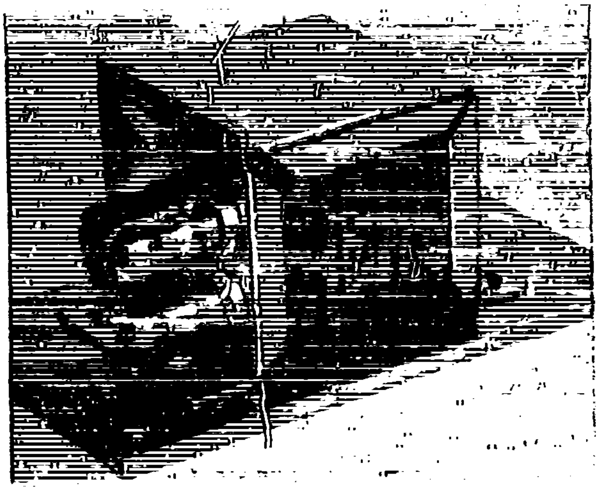


Figure 8-1-11. Variable Resistance Type Pressure Transducer

1.2.2.3.2 Variable Reluctance Type. (See Figure 8-1-12.) Variable reluctance type pressure transducers are commercially available. For parachute system tests, they are most commonly used in connection with telemetering systems. Tranducers in a range between 0.1 and 30 psi are being used in parachute systems applications.

A disadvantage is the necessity of maintaining constant temperature for accurate indications.

Figure 8-1-12. Variable Reluctance Type Pressure Transducer

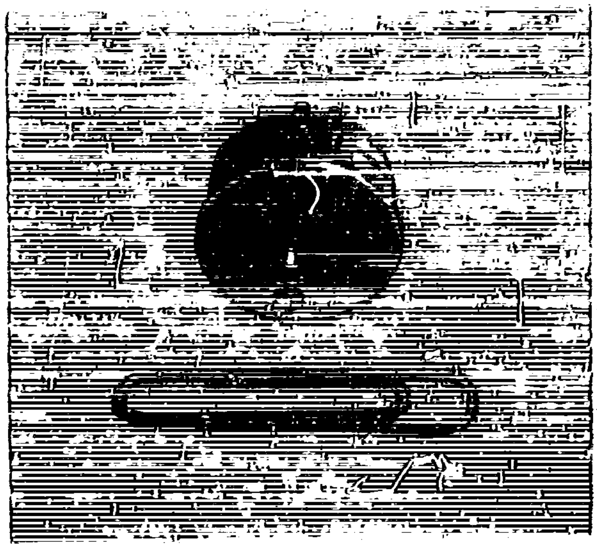


Figure 8-1-13. Miniature Differential Pressure Transducer

Models are available for measuring altitude by static pressure. Their range is from 0 to 75,000 ft.

1.2.2.3.3 Miniature Differential Pressure Transducer. (See Figure 8-1-13.) For the purpose of measuring the differential pressure at various points on the parachute canopy, a miniature pressure transducer was developed by Gulton Manufacturing Company, Metuchen, New Jersey. The transducer itself embodies the smallest possible size and weight commensurate with acceptable accuracy and reliability. This transducer senses a differential air pressure and changes it into an electrical signal, which can be utilized by presently available measuring and recording equipment. Three ranges of differential pressure transducers were developed: 0 to ± 100 mm mercury, 0 to ± 5 psi, and 0 to ± 10 psi. The frequency response of low-range sensing element is 200 cycles per second. The natural frequency of all sensing elements is 5 kilocycles or higher. Air damping is utilized. The linearity is better than 1.5 percent of full scale. Its hysteresis is better than 0.5 percent of full scale. Its temperature range is from -67° to +120° F. Its sensitivity is larger than 2 millivolts full scale per volt input, and its zero shift is less than 0.02 percent of full scale per degree F. These same conditions apply to all three types, with the exception of frequency response, which is 300 cycles per second for the 0 to ±5 psi transducer and 400 cps for the 0 to ±10 psi transducer. The diameter of the sensing element

is 3/4 inch and its thickness is 3/8 inch. The transducer may be applied to the parachute cloth by means of a clamping ring. The parachute cloth actually is clamped between the sensing element and this ring. The unit is sensitive to differences of pressure applied to the two opposite sides. Openings on each of the flat faces permit the pressure to be applied to an internal diaphragm, which deflects in proportion to the differential pressure. As the diaphragm moves due to a differential pressure acting upon it, a mu-metal slug attached to the diaphragm changes the reluctance of the two magnetic circuits. By utilizing this unbalanced effect between the two coils in the proper electrical circuitry, it is possible to measure the current, which is proportionate to differential pressure.

Generally, the instrument is used in a bridge circuit, where the change in impedance of the two coils in the transducer unbalances the circuit. This circuit unbalance causes a current flow which is easily measured. Errors originating from imposed acceleration upon the sending element are less than 0.2 percent of full scale per g.

1.2.2.4 Displacement Transducers.

1.2.2.4.1 General. (See Figure 8-1-14.) All displacement transducers used for the measurement of displacement in the field of parachutes are based upon resistance changes. Various types of rectilinear transducers are commercially available, ranging for strokes between 1/4 in. and 3 in. The relative motion between the instrument case and the plunger attached to the suspension line or riser will change the pickup resistance of the potentiometer. This sensing element may be connected in a bridge circuit or used as a potentiometer.

1.2.2.4.2 Miniature Rectilinear Displacement Transducer. (See Figure 8-1-15.) For the purpose of measuring stresses in parachute cloth, suspension lines, or webbings, a miniature rectilinear displacement transducer was developed by Colvin Laboratories, East Orange, New Jersey. This displacement transducer has a nominal stroke of 0.25 inch. Its resistance measures 1,000 ohms. The displacement transducer is linear within a very small percentage of full scale. Gravitational forces of up to 60 g's applied along an axis parallel to the plunger axis, and of 30 g's applied along any axis perpendicular to the plunger axis, do not cause electrical discontinuity, damage to the instrument, or change in pickoff resistance. The sensing element may be either glued or sewed to the material to be tested. Relative motion between the sensing element case and the plunger is translated into a resistance change and is proportional to the elongation of the material used. It is planned to use this sensing element on parachute canopies to measure elongation of particular types of cloth during the opening sequence of the parachute canopy, or to determine elongation in riser or suspension lines during force application. These displacement transducers may be used in connection with oscillographs, tape recording systems, telemetering systems, or direct reading instruments.

1.2.2.5 Rate of Descent Transducers. (See Figure 8-1-16.) A rate of descent transducer

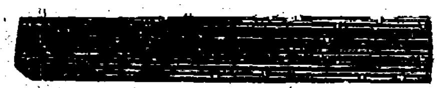


Figure 8-1-14. Rectilinear Displacement Transducer

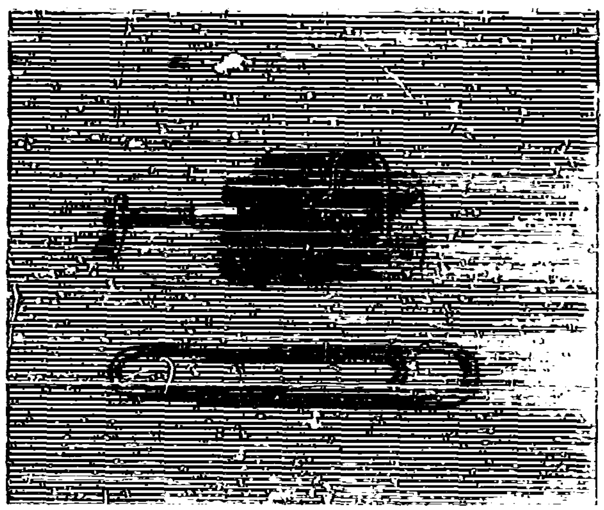


Figure 8-1-15. Miniature Rectilinear Displacement Transducer

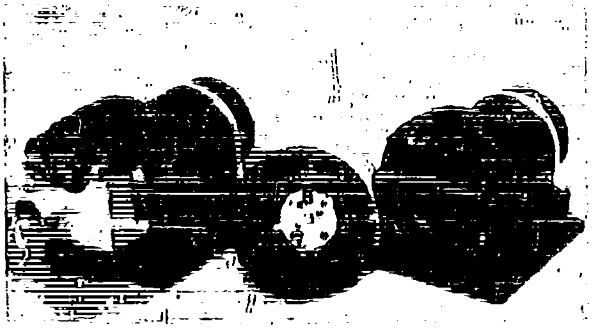


Figure 8-1-16. Rate of Descent Transducer

was developed in connection with the magnetic tape recording system by Cook Research Laboratories, Skokie, Illinois. The rate of descent transducer consists of a mechanical-electrical mechanism which transforms varying air pressure changes into terms of varying d-c voltage changes. The mechanism consists of a vertical speed indicator working simultaneously with a motor-driven gear arrangement. The vertical-speed indicator operates on the principle of varying air pressure due to change in altitude, producing a pressure in the indicator case lagging behind the pressure in the diaphragm. The lag in pressure is caused by a capillary restriction in flow of air into and out of the case. This resulting differential pressure actuates the mechanism producing a pointer deflection. The pointer in this case is of aluminum, on the end of which is a platinum cat whisker mounted on a dual bearing. The cat whisker is mounted between four platinum wire terminals to which are connected two voltages of opposite polarity. Under quiescent conditions, the cat whisker rests between terminal contacts. However, when a pointer deflection occurs because of descent, the cat whisker is driven to two of the contacts completing a circuit, which closes a relay, which in turn puts a voltage of proper polarity to a d-c motor. This motor drives a shaft and wiper, which revolves about a helipot. Any change in helipot resistance produces a corresponding d-c voltage output change. When the vertical speed indicator pointer deflects in the opposite direction because of loss in rate of descent, the drive motor is also accelerated in the opposite direction, producing a corresponding voltage change. This d-c voltage is applied directly, either into the input of the tape recording system or, if an oscillograph is used, into the galvanometer circuit. The range of this rate of descent transducer is between 0 and 100 feet per second. A 24-volt d-c input is required to operate the sensing element.

1.2.2.6 Oscillation Transducer. (See Figure 8-1-17.) In connection with the magnetic tape recording, two types of oscillation transducers are used. First, rate gyros modified with inductive elements, and second, position gyros with resistive elements. Both types of gyros are commercially available in various ranges. The rate gyros presently used will require a 24-volt, 400-cps power supply to drive the gyro, while the position gyro is d-c operated. Both gyros are rather bulky and can only be used for applications in heavy cargo load drops. They are not suitable for parachute dummy drops, because of space restrictions.

1.2.3 SELF-RECORDING INSTRUMENTS (DROP TEST).

1.2.3.1 General. Self-recording instruments are used for a majority of parachute tests, particularly during the early stages of parachute development. The use of these instruments is economical, and recordings within satisfactory accuracy limits can be obtained. The following types of self-recording instruments have been developed and are being used for parachute applications.

1.2.3.2 Tensiometer. Knowledge of magnitude and duration of forces during parachute deployment and descent is of the utmost value in parachute research and development. Particularly during quantitative tests, a mechanical recording tensiometer has proven to be more advantageous than any electronic recording device used. Two types of tensiometers have been developed and are being used during parachute test programs.

1.2.3.2.1 Embossing Stylus Type. The magnitude and duration of forces, as well as a

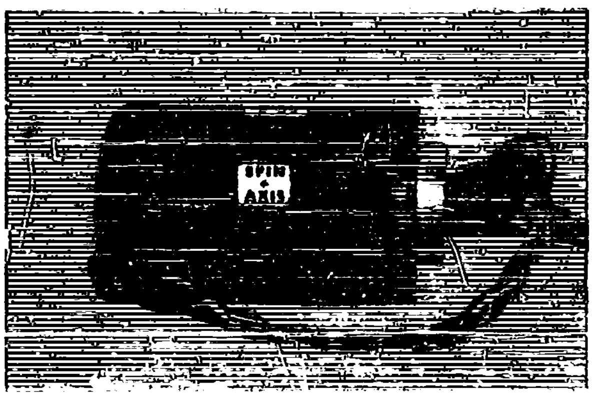


Figure 8-1-17. Gyro Controlled Position Transmitter

time scale, are recorded on a moving strip of polished aluminum foil by embossing styli. The force stylus follows the movement occurring when the force transmitted through the instrument deforms the individual units of a column of radially tapered disc springs. The overall assembly view is shown in Figure 8-1-18. The dummy load is attached to the lower clevis with an appropriate harness, while the upper clevis is attached to the parachute suspension point or riser. Operation is initiated by a pull cord. The component parts of the instrument can be grouped into four operational units:

a. A round aluminum casing to which two clevises are attached.

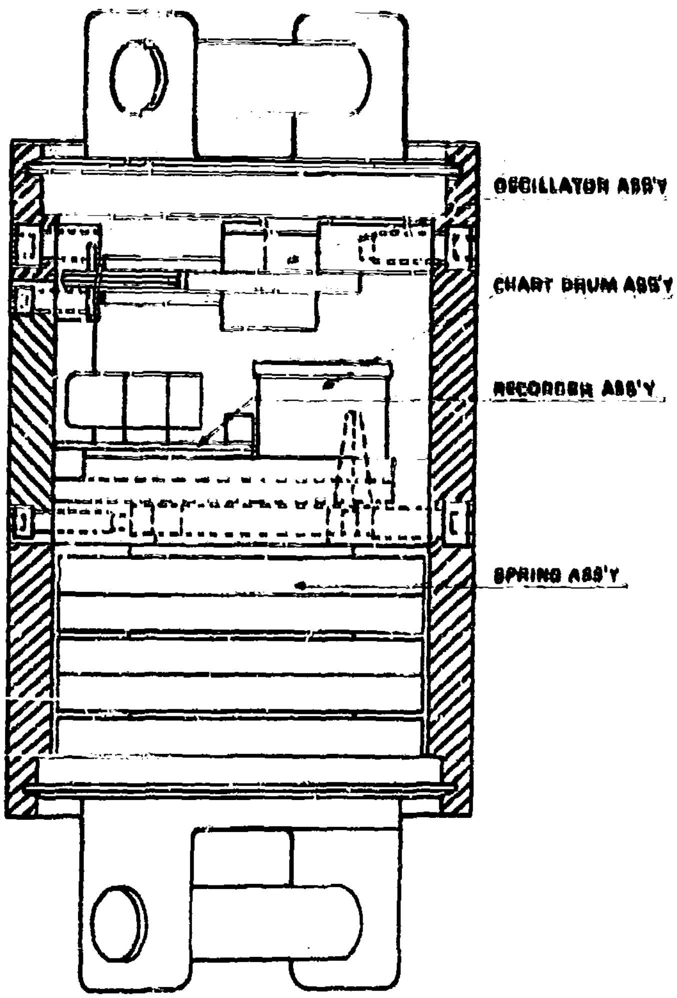
b. A column of steel disc springs on a pull rod supporting the force stylus.

c. The chart drive mechanism, consisting of the recorder assembly and the chart drum assembly.

d. The time marker mechanism, consisting of the oscillator and the time marker.

The casing for the instrument is made out of round stock aluminum capable of supporting a radial load of 16,000 pounds. The upper and lower clevises are attached to the casing and pull rod. An access window in the casing is provided for easy removal of the recording unit. Tension applied to the instrument is transmitted through the casing and the pull rod from the clevises.

A column of radially tapered steel disc springs, mounted on the pull rod, is housed in the lower portion of the instrument. When compressed, these springs have nearly linear deflection for



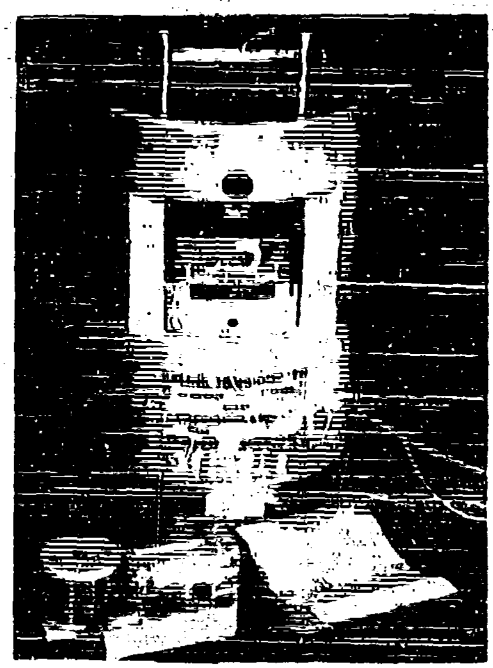


Figure 8-1-18. Embossing Stylus Type Tensionmeter

maximum rated load. To prevent any looseness in the spring assembly, which would disturb the zero-line, a preload is imposed on the spring system. A bar, supporting the force stylus, is screwed in place in a slot across the head of the pull rod. The projecting ends of the bar are used as guides to prevent any rotation of the pull rod due to angular accelerations acting upon the instrument. The force stylus is mounted in two cantilever springs, which are soldered into slots near the end of the bar. The stylus must deflect slightly when the chart drum is placed in position; thus, its location is somewhat critical, since the stylus must always act with only a slight force against the recording medium. The natural frequency of this force recording system is approximately 700 cps.

The recorder assembly consists of the escapement mechanism and the chart drum assembly. The escapement mechanism construction is much more rigid and shockproof than that commonly used in spring powered clock construction. The escapement is started by the movement of a slider bar, which is actuated by a pull cord. Battery current to the oscillator is connected by the same motion. After one complete turn of the drive shaft, the escapement is stopped and battery current disconnected. The edges of the recorder base plate are beveled to fit into the dovetails milled into the guide plate of the instrument. The moment of inertia of the rotating system is sufficiently low when compared to that of the torque spring. This is essential to prevent any slowing down of the clock as a result of angular accelerations which might be imposed on the system externally. The chart drum is designed to hold the recording medium in a true cylindrical shape. The recording position is made of polished aluminum foil approximately 0.003-inch thick. It is preformed to a cylindrical shape slightly smaller in radius than the drum surface and firmly held in position on the chart drum.

The function of the oscillator is to interrupt the battery current periodically to cause the time marker to record the desired time intervals on the recording medium. The oscillator is of electromechanical design and particular attention is given to ensure that it be free of inertia and acceleration effects. The frequency of oscillation depends upon the moment of inertia of the two soft iron discs, each mounted on pivot bearings to rotate about its own axis, and the value of the restoring torque of the straight wire springs connecting the two discs. The nominal frequency of the oscillator is 20 cps.

The time marker is a simple solenoid magnet carrying a pivoted armature. On one end of this armature is a spring-loaded stylus. The time marker solenoid is connected in series with the oscillator solenoid. Thus, each oscillation of the oscillator disc causes the time marker armature to move up and down. The time marker stylus is located slightly above the force stylus inside the instrument case. The force sensing system is calibrated by subjecting the instrument to known forces and recording the position of the stylus on the recording medium. The deflection of the spring column when subjected to a load of 1,000 pounds is approximately 0.014 inch.

For the purpose of evaluating the recorded information, it is necessary to magnify the recorded trace. A toolmaker's microscope is satisfactory to evaluate individual force values. To obtain force versus time histories, other conventional reproducing devices may be used.

The overall length of the instrument is 8.5 inches, and the diameter of the instrument case is 4 inches. The weight of the instrument is 11.2 pounds.

Advantages of this instrument are:

a. The record of the forces recorded may be read even after almost complete destruction of the instrument.

b. Relatively inexperienced personnel may be used for installation, loading, and unloading of the instrument.

Disadvantages are:

a. The adjustment of the force stylus is critical in order to produce a visible record and avoid gouging.

b. The frequency response of this instrument is relatively low and, therefore, the application of the instrument is limited.

The following types have been developed and are available:

Type I — Capacity 7,500 lb., 10 seconds recording time
Type II — Capacity 7,500 lb., 20 seconds recording time

Type III — Capacity 15,000 lb., 20 seconds recording time

This self-recording tensiometer was developed by Exline Engineering Co., Tulsa, Oklahoma, and was assigned the Model No. D-104.

1.2.3.2.2 Photographic Type. The magnitude and duration of forces, as well as a time scale, are recorded on a moving strip of 35-mm. photo-sensitive film by means of light beam recording. The overall assembly view is shown in Figure 8-1-19. The use of this instrument and the starting procedure of the recording cycle are identical to those described in the previous paragraph. The force sensing and recording system operates as follows: An annular disc spring is deflected slightly under load, and this deflection causes an angular rotation of a small mirror. The image of an illuminated slit is focused on a narrow aperture in front of a moving strip of photo-sensitive film after reflection from the rotating mirror. As this mirror rotates, the image is caused to move lengthwise along the aperture, so that the developed film shows the displacement of the image as a curved line. A fixed mirror, closely adjacent to the rotating mirror, provides a stationary image near one end of the aperture and produces a straight reference line on the developed film. The natural frequency of the force sensing and recording system is approximately 1,200 cps.

The recorder assembly contains a commercially available 35-mm. film magazine and is fastened light-tight to the instrument case window. Upon recorder insertion into the instrument, a gear on the takeup reel of the recorder meshes with the drive gear of the spring motor and the instrument is ready for operation.

The drive motor for the recorder is a Neg'ator type spring motor of sufficient torque to pull the recording medium past the aperture with constant speed for a minimum period of 20 seconds. Recording time may be changed by adjusting the governor on the spring motor.

A small neon bulb, located near the aperture, is caused to flash with a constant frequency from a vacuum tube oscillator. Each flash illuminates the aperture. The developed film then shows a series of lines across the film, the distance between any two successive lines representing a time interval of 0.04 second.

The force sensing system is calibrated by subjecting the instrument to known forces and recording the position of the deflected light beam on the film strip. An applied maximum rated load to the force sensing system of the instrument corresponds to a light beam deflection on the recording medium of approximately 0.75 inch.

The recording may be reproduced for evaluation by means of a photographic reproduction device which prints the recording traces and a calibration grid on a standard size sheet of photographic paper.

The overall length of the instrument is 11 inches, and the diameter of the instrument case is 4 inches. The weight of the instrument is 11.45 pounds.

This tensiometer allows the recording of forces of very short duration with great accuracy. While it does not require highly skilled personnel to maintain this instrument, the recording accuracy that may be obtained is substantially higher than that of the embossing stylus type tensiometer. This instrument was also developed by the Exline Engineering Co., Tulsa, Oklahoma, and is being manufactured under Model No. BX-101. The following types are available:

- Type I — Capacity 4,000 lb., 10 seconds recording time
- Type II — Capacity 7,500 lb., 10 seconds recording time
- Type III — Capacity 7,500 lb., 20 seconds recording time
- Type IV — Capacity 15,000 lb., 20 seconds recording time

1.2.3.3 Accelerometer. (See Figure 8-1-20.) A self-recording accelerometer was developed by Gulton Mfg. Co., Metuchen, New Jersey, for the purpose of measuring and recording gravitational forces during exploratory parachute drop test. This self-recording accelerometer is designated as Glenite Tape Recording System KAT-1. The Glenite Tape Recording System has been designed to provide for the instantaneous recording of gravitational forces in moving devices where direct or wireless connections between transducer and recording system are not feasible. The system consists of two basic devices, a completely self-contained, self-recording accelerometer, which provides a coded acceleration versus time record on magnetic tape, and a tape playback unit, which can drive permanent recording devices, such as a light-beam galvanometer. In application, the tape record is made within the accelerometer. This is folowed by removal of the

tape, which is then played back in the playback system. The self-recording accelerometer consists of the seismic transducer, the electronic circuitry, and the tape transport mechanism. The self-recording accelerometer provides a 30-second instantaneous

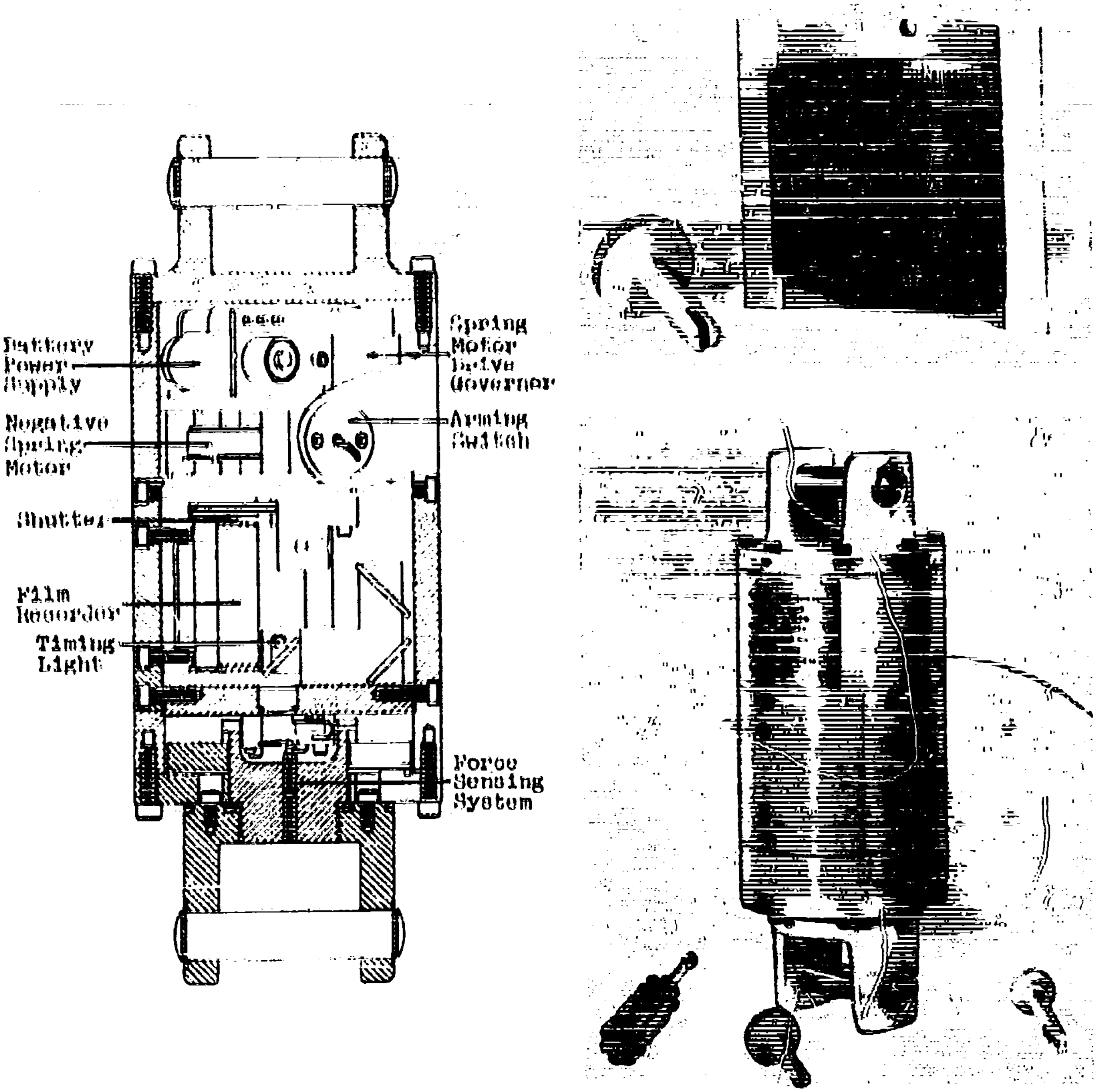
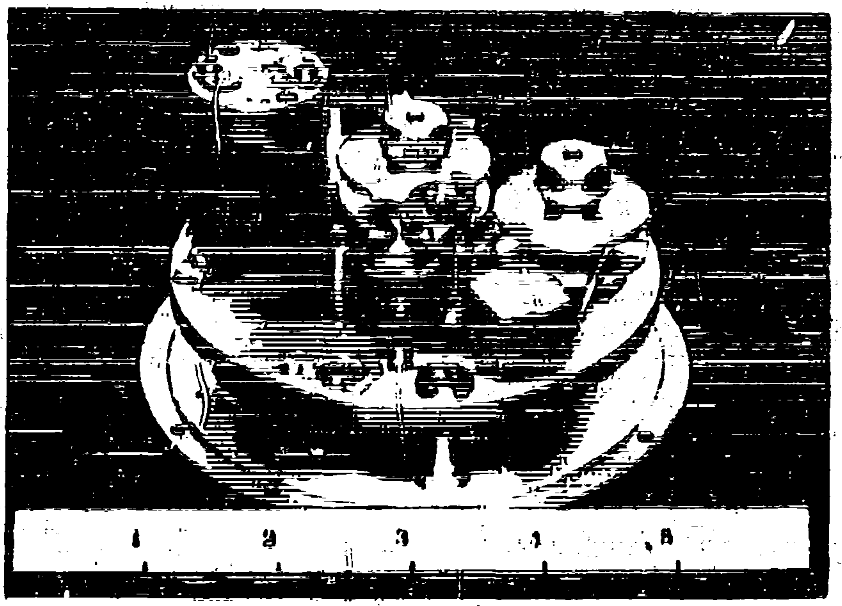
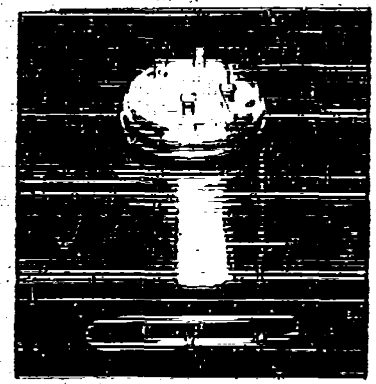


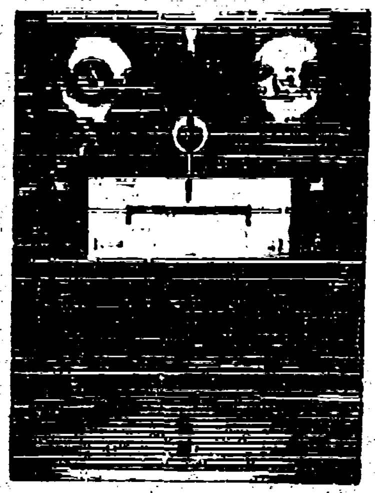
Figure 8-1-19. Photographic Type Tensiometer



Electrically Driven Recording Mechanism



Recording Circuit



AP-1 Playback System

Figure 8-1-20. Self-Recording Accelerometer

tape record of shock and acceleration phenomena. It is packaged within a housing 4 1/2 in. in diameter and 3 in. high, and weighs only 3 lb. complete. This accelerometer can be mounted in relatively inaccessible locations in moving objects. The unit is completely self-contained, and only the pull of a cord or the action of a contact pair is necessary to start the recording action. This accelerometer was developed for installation in the center tube of a parachute dummy.

1.2.3.3.1 Seismic Transducer. The seismic transducer is a differential transformer device utilizing a spring suspension. The unit operates over a range of acceleration from 0 to ±160 g. However, careful balancing techniques provide full scale measurements down to ±10 g's. The undamped natural (resonant) frequency of the transducer is about 500 cycles per second. Fluid damping to 0.707 of critical at 26° C. ensures flat frequency response from 0 to 300 cps. The seismic transducer is mounted to the inside of the top plate of the accelerometer and produces a carrier modulated output proportional to the instantaneous acceleration.

1.2.3.3.2 Electronic Circuitry. The entire electronic circuit, cast in resin for extreme ruggedness, is fastened to the inside of the cover plate. The electronic circuitry is completely transistorized to reduce size and weight, to minimize battery power consumption, and to obtain instantaneous starting. A phase modulation technique has been developed for this instrument. One of the features is that both reference and information signals are recorded on a single track of tape. While both are used to decode the data in the playback system, the reference signal may also be used as a timing signal on the final playback record.

1.2.3.3.3 Tape Recording Mechanisms. The tape transport mechanism, electrically driven by a self-contained battery, is designed to drive the magnetic tape at a speed of 15 inches per second. This provides a running time of 30 seconds, using 500 inches of 1/4-inch-wide magnetic tape. The entire mechanism is designed into a housing to withstand high external forces, and the system is designed to operate with less than ±10 percent speed variation at accelerations up to ±60 g's. The tape transport mechanism is normally supplied with a pull-wire starting switch designed to energize the complete accelerometer with 10-lb. tension. Other starting devices may be used, such as relays or acceleration switches. For normal use, an automatic stop mechanism is provided, which breaks the motor battery circuit as soon as the last portion of tape passes the head.

1.2.3.3.4 Playback Unit. The playback system is required to process the phase modulated tape recording to obtain a signal containing the required acceleration-time characteristics. This unit consists of two components mounted in a single rack, approximately 22" x 18" x 28". A high-quality playback transport device provides playback at 15 in. per sec, and will handle spliced records up to 1,200 ft. The instantaneous filtered output of the playback unit is fed to standard recording devices, such as galvanometers, oscilloscopes, meters, or direct writing recorders.

1.2.3.4 Oscillometer. (See Figure 8-1-21.) A self-recording oscillometer was developed by Exline Engineering Company, Tulsa, Oklahoma, for the purpose of sensing and recording the amplitude and period of oscillation of a parachute suspended load during descent. The oscillometer incorporates two angular position sensing elements to sense oscillations in two mutually perpendicular axes. These position-sensing elements are essentially frictionless bearings caged in a zero or neutral position and, after a predetermined time interval, released. The relative position between the rotor and stator of the sensing elements is recorded on a moving 16-mm. filmstrip. Operational sequence of this instrument is initiated by removal of an arming cable. This action arms an accelerometer type sensing device set to actuate at a selected value of gravitational force imposed upon the element. The opening shock of the parachute will actuate this sensing device and arm a time delay circuit. After a preset time, the time delay circuit will cause angular position sensing elements to uncage and, at the same time, start the 16-mm. filmstrip contained within a U.S.A.F. camera, which is modified for a 6-volt d-c drive motor. After a preselected time interval, the camera will stop and the angular position sensing elements become caged again. Two types of self-recording oscillometers have been developed and are available. Type I was designed for use during routine, low-altitude drop tests. The range of this instrument is ± 45° and the recording continuous with adjustable recording periods of 20, 40, and 60 seconds. Type II was designed for high-altitude testing of experimental parachutes. The range of this instrument is ± 60°. The total recording time is divided into four recording intervals of 30 seconds each. Each recording period is initiated by one of four aneroid switches, which are preset to initiate the individual recording periods at certain altitudes. Altitude selections may be made within the following pressure altitude ranges: sea level to 25,000 ft., 25,000 to 50,000 ft., 50,000 to 75,000 ft., and 75,000 to 100,000 ft.

The entire instrument, with the exception of the power supply, is housed in a container approximately 19 1/2 inches long and 4 7/8 inches in diameter. This instrument may be inserted into the center tube of a parachute drop test

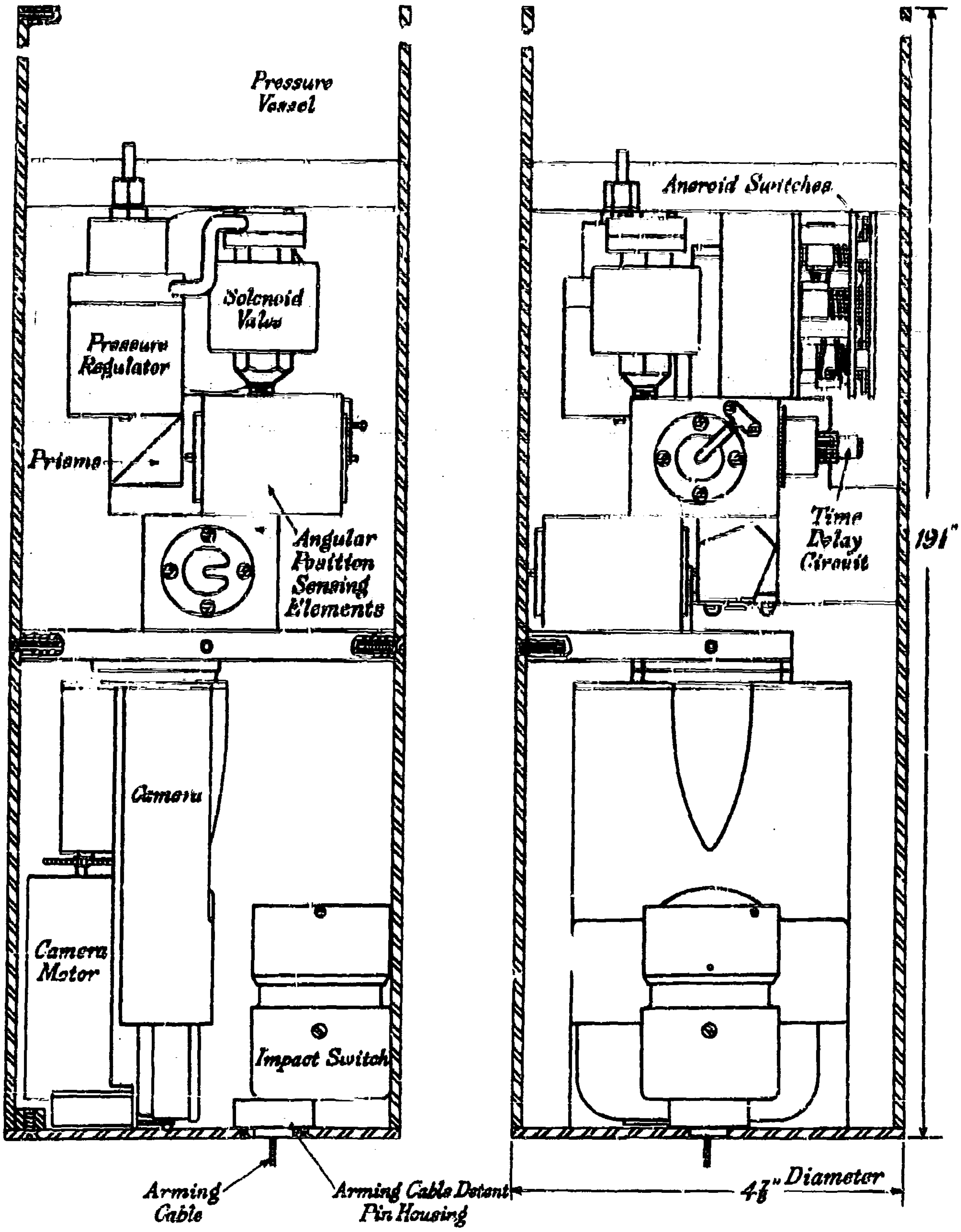


Figure 8-1-21. Self-Recording Oscillometer

dummy. The power supply is housed in a container approximately 6 inches long and 3 7/8 inches in diameter, and contains a battery power supply sufficient for the operation of the self-recording oscillometer and heating elements located in the instrument proper and the power supply container. This power supply container may be inserted into one of the arm tubes of a parachute drop test dummy.

All instruments mentioned above are designed to record data on a single channel only, with the exception of the oscillometer, which will record two channels of oscillation in two axes.

1.2.4 SELF-RECORDING INSTRUMENT SYSTEMS (DROP TEST).

1.2.4.1 General. These instrument systems are used for the measurement and recording of various parachute phenomena versus a common time base. The instrument systems available fall into two general categories, the magnetic tape data recording systems, and the telemetering systems.

1.2.4.2 Magnetic Tape Data Recording Systems. The magnetic tape data recording system was developed and constructed by Cook Research Laboratories, Skokie, Illinois. The purpose of the data recording system is to take amplitude-modulated signals, either ac or dc, from various types of sensing elements, convert them into frequency-modulated audio signals between 3,000 and 4,000 cps, and record these signals on magnetic tape. The magnetic tape data recording system provides a complete means of recording simultaneously the data supplied by a number of sensing elements. The equipment is designed to accept information signals from such instruments as accelerometers, tensiometers, pressure transducers, altimeters, and airspeed indicators, and to convert these signals into a form acceptable to the magnetic tape recorder. A fixed frequency of 4,000 cps from a reference frequency oscillator is also recorded on one channel on the magnetic tape for the purpose of error compensation and tape speed control in the playback system. Auxiliary equipment provided with this system consists of a field calibration unit that allows the accurate adjustment of the individual converter channels as well as reference frequency channels. The components of the equipment generally consist of sensing elements, signal converters, reference frequency oscillator, magnetic tape recorder, and power supply motor-alternator.

a. Signal converters are electronic circuits used to convert the signals obtained from various types of sensing elements to variable audio frequencies, which are recorded on the magnetic recording tape. The audio-frequency shift thus obtained is proportional to the output received from the sensing element. Two types of signal converters may be used with this system, the a-c type and the d-c type. The a-c signal converter uses a 1,400-cps carrier voltage and will accept signals as low as 0.009 volt, at 1,400 cps from the sensing element at full-scale deflection for a 1,000-cycle shift. This circuit is specifically designed for operation with sensing elements having a low output voltage. The d-c converter is used with sensing elements having in the neighborhood of 5 volts of d-c output. These units require approximately 4.3 volts dc for full-scale deflection.

b. Reference frequency oscillator supplies a fixed frequency of 4,000 cps to a single channel on the magnetic tape recorder. This signal is subsequently used as a reference signal in the playback system to compensate for variation in tape speed and to control the speed of the playback unit so that it is identical to the speed of the recorder during the time of recording. The oscillator output amplifier circuit is identical to that of the signal converter.

c. Magnetic tape recorder is used to convert the output of the various signal converters into a magnetic pattern on the recording tape.

d. Power supply and motor alternator. The motor alternator contained within the power supply component is used to convert the 24-volt nominal battery supply voltage to a 40-volt, a-c, 1,400-cps supply voltage for use in the power supply for zero adjust voltage in signal converters and as a voltage source for bridge type sensing elements. The alternator delivers approximately 11 watts with an output of 38 volts. The power supply furnishes the plate voltages for all the electronic circuits. All

oscillator tubes require a well-regulated plate voltage and a well-regulated filament supply. Plate voltage regulation is accomplished by means of an electronic voltage regulator, which utilizes both sections of a dual triode tube. The filament voltage is obtained from a separate 12-volt power supply. All amplifier tubes require 140 volts dc for plate voltage. In addition, the power supply also furnishes the required values of voltage at 1,400 cps for signal converter, zero adjust, and carrier voltage. Carrier voltages may be furnished between 10, 14, 18, and 20 volts ac. A number of magnetic tape recording systems have been developed and constructed in the past for various applications. They are all built around the basic component described above.

1.2.4.2.1 Drop Test Gondola. (See Figure 8-1-22.) This item is a drop test bomb which contains a number of sensing elements, converters, power supplies, and recorders in order to measure and record various parachute phenomena versus a common time base during one drop. The gondola weighs approximately 250 pounds when fully loaded, including test parachutes. The test parachute is generally packed in a deployment bag and stored in the inside of the tail section of the gondola, which may be ejected forcibly after a predetermined time. The gondola may be carried either externally or internally in an aircraft. The following parachute phenomena may be measured:

a. Parachute force versus time.

b. Gravitational forces parallel to the longitudinal axis of the test gondola.

c. Gravitational forces in both the X- and Y-axes, that is, 90° to the longitudinal axis of the test gondola.

d. Airspeed.

e. Altitude, from which rate of descent may be extracted.

f. Oscillation of the parachute system in two axes.

Generally, oscillation in both axes is recorded after a predetermined time has elapsed from the moment of parachute deployment. An intricate timing system is provided in the test gondola to preselect the time of tail [illegible]ation from the gondola and to preselect the [illegible] at which the oscillometer channels will be [illegible]hed into the systems. A number of different tail configurations have been designed for the test gondola and have been used in the past in order to make it possible to test parachutes utilizing different deployment methods. Originally, the ejected tail acted as pilot chute to deploy the main parachute or test parachute, which was stowed in a deployment bag. Parachutes in sizes up to 28 feet may be tested. However, since the system is relatively expensive, the test gondola is used only for drop tests on parachute systems that have previously proven their reliability. Two 24-volt power supplies are carried internally in the gondola. Data is recorded on one-inch-wide magnetic tape. The overall recording time of this recorder is 25 minutes. Operation of the entire system has been tested at ground impacts up to 75 g's. In order to prevent damage to the instrument system, a crushable nose section is provided, which may be replaced after each drop test.

1.2.4.2.2 Six-Channel Magnetic Tape Recording System (Universal). (See Figure 8-1-23.) This system consists of individual components comprising six signal converters, each individually housed in steel containers 3 15/16 inches in diameter and 2 7/8 inches high, a power supply and motor-alternator set, together with three variable resistance type accelerometers, which are housed in a steel container 4 7/8 inches in diameter and 9 inches high, a magnetic tape recorder and reference frequency oscillator housed in a steel container 4 7/8 inches in diameter and 9 inches high, and two battery units, each containing two 6-volt lead-acid batteries, mounted in a steel mounting 3 15/16 inches in diameter and 3 5/8 inches high. This particular system is used for cargo applications or may be installed in the different internal tubes of a parachute dummy. Six different phenomena may be recorded versus a common time base. The overall weight of the complete system is approximately 70 pounds. This system, too, has been tested under shock loads of up to 75 g's. The magnetic tape recorder accommodates tape one-inch wide and has a recording time of 3 minutes, with an average tape speed of 11 inches per second.

1.2.4.2.3 Six-Channel Magnetic Tape Recording System (Single Unit). (See Figure 8-1-24.)

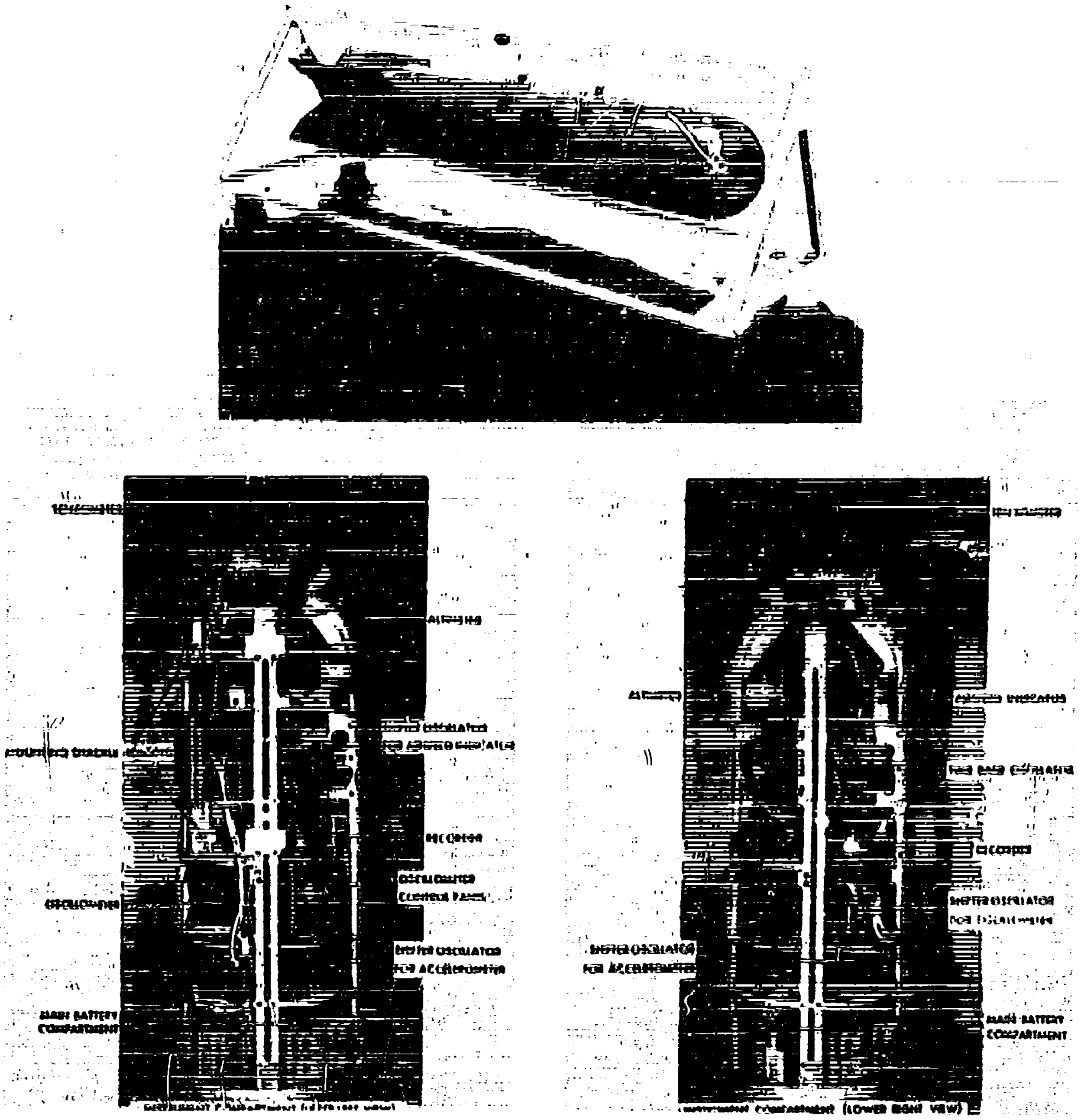
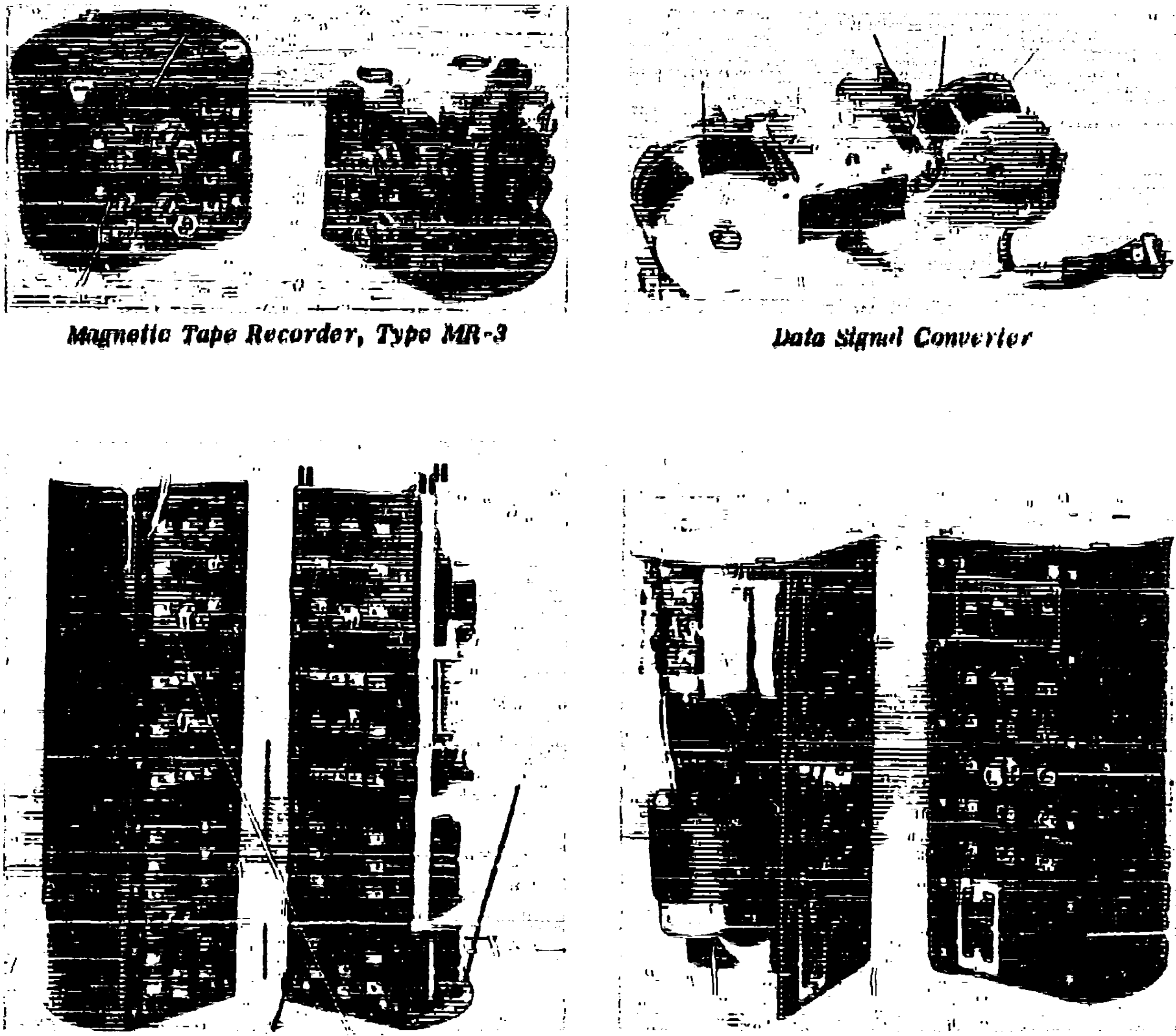


Figure 8-1-22. Drop Test Gondola

This system, which is used particularly for heavy cargo drop test applications, contains all components within one unit. The overall dimensions of this system are 24 inches long, 18 inches wide, and 12 inches high. Six data channels, power supplies, and a reference frequency channel are included in this system. A 24-volt, d-c power source is used to power the electronic components and the tape recorder. A calibration unit is included by means of which it is possible to simulate full-scale deflection on sensing elements by switching precision



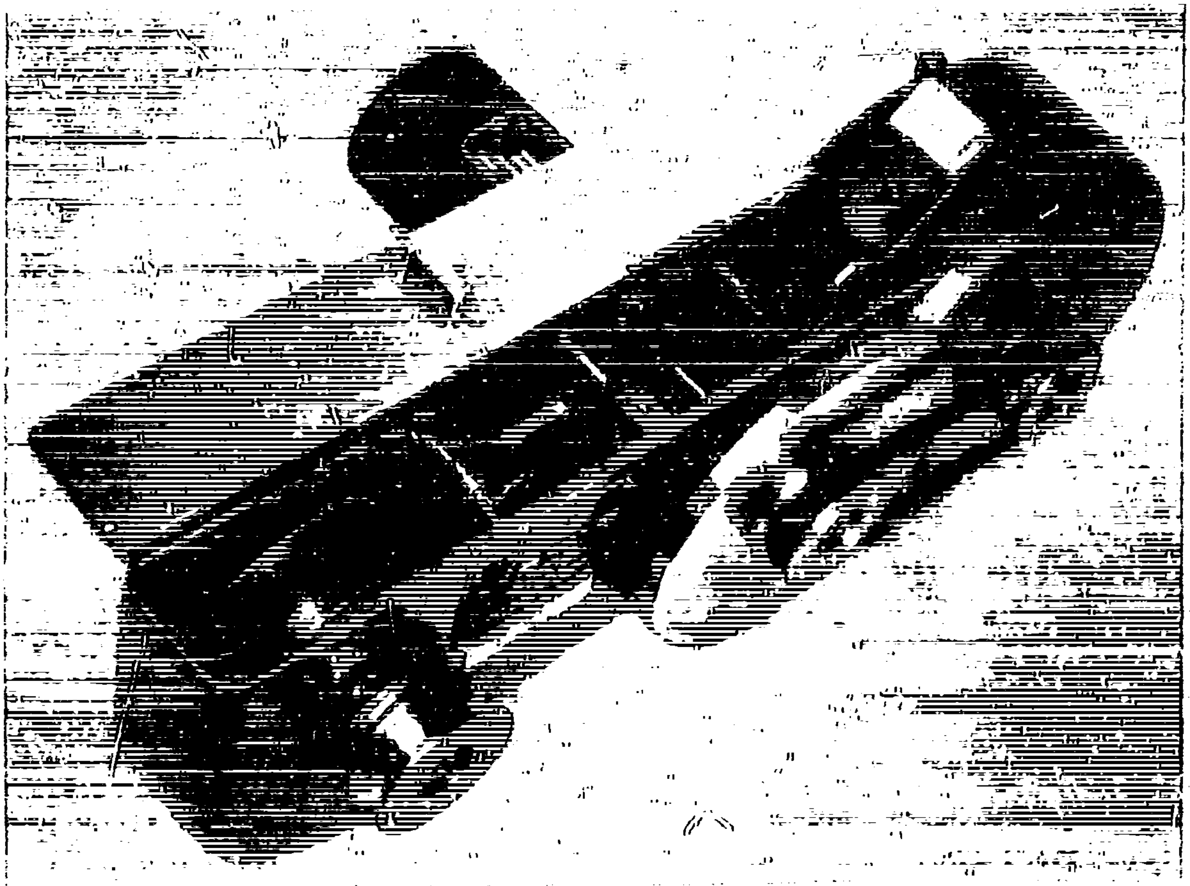
Magnetic Tape Recorder, Type MR-3 *Data Signal Converter*

Power Supply *Recorder Container*

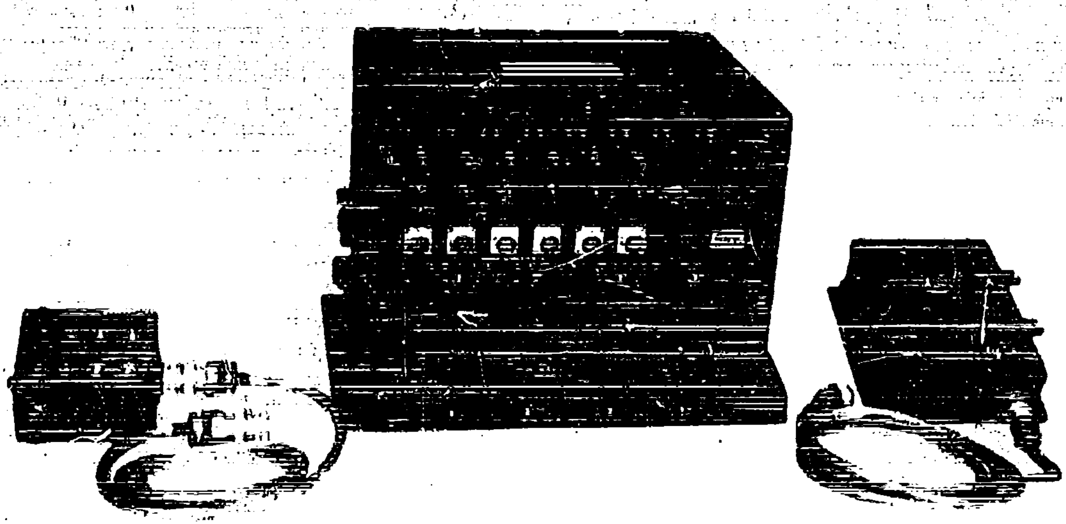
Figure 8-1-23. Six-Channel Magnetic Tape Recording System (Universal)

resistors into the sensing element input circuits. The tape recorder in this system is built particularly rugged in order to record under sustained high gravitational forces of up to 75 g's. The overall running time of this recorder is three minutes and the average tape speed is 30 inches per second, which results in a much smoother playback recording.

1.2.4.2.4 Miniature Tape Recording System. (See Figure 8-1-25.) Only recently, two miniature tape recording systems were developed for installation into the internal tubes of a parachute dummy. One system consists of three data channels and one reference frequency channel, while the other consists of six data channels and one reference frequency channel. The overall dimensions of this system are approximately 5 inches in diameter and 23 inches long. The auxiliary equipment required for the operation of this system consists of a power switching unit, calibration unit, and power supply. The power switching unit may be installed in the right-arm tube of a parachute dummy and has as its function the switching from externally to internally applied d-c power. The left-arm tube of the dummy contains the calibration unit, by means of which it is possible to simulate full-scale sensing element deflection by switching a known resistance into the input circuits of the data signal converters. The two leg tubes

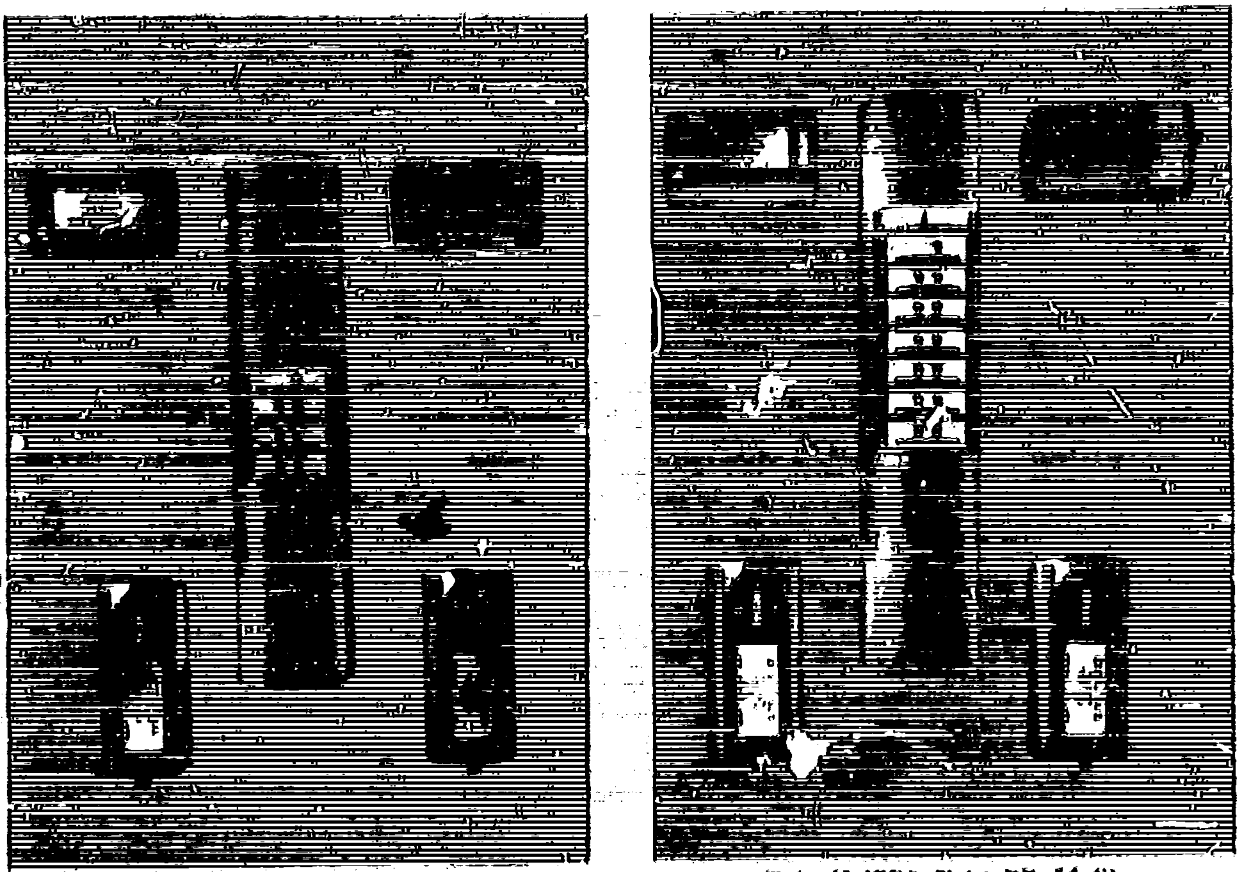


Magnetic Tape Recorder, Type MR31A



Data Recording System, Type DR-12-6

Figure 8-1-24. Six-Channel Tape Recording System (Single Unit)



Type I (CRL Type DR-14-3) *Type II (CRL Type DR-14-6)*

Figure 8-1-25. Miniature Tape Recording Systems

of the parachute dummy contain a 24-volt, d-c power supply for the operation of the system. Tests have been conducted on this system up to altitudes of 100,000 feet and temperatures down to -65° F. The tape recorders in both systems are miniaturized and have a recording time of three minutes, with an average tape speed of 11 inches per second. For the three-channel system, 1/2-inch-wide magnetic tape is used, while 1-inch-wide tape is used for the six-channel system.

The operational characteristics and the components of the magnetic tape playback system are described under "Laboratory Instrument Systems."

1.2.4.3 Telemetering System. (See Figure 8-1-26.) Essentially, telemetering is a means whereby intelligence data are measured in flight and transmitted to a ground station for record and interpretation. Many systems have been developed, but for most parachute system tests, only miniature or subminiature systems can be used.

1.2.4.3.1 FM/FM Telemetering System. Each intelligence datum measured is converted into an equivalent electrical signal, which frequency-modulates a subcarrier oscillator operating in one of the standard Research and Development Board (RDB) subcarrier bands. The output voltages of the subcarrier oscillators are combined and applied to the modulator circuit of a V-H-F radio transmitter, which in turn excites a transmitting antenna. The signal is recovered by a ground station receiver, which converts the F-M R-F signal into a composite subcarrier voltage. Bandpass filters separate the individual subcarrier voltages from the composite signal. The filtered subcarrier signals are fed into subcarrier frequency descriminators, which produce a varying d-c output voltage. The current output of the discriminator is the electrical equivalent of the original stimulus. This output may be fed into a galvanometer type recording oscillograph to convert the electrical signals into a permanent photographic record. By the use of a conversion or calibration chart, or by automatic data reduction equipment, the information may be converted

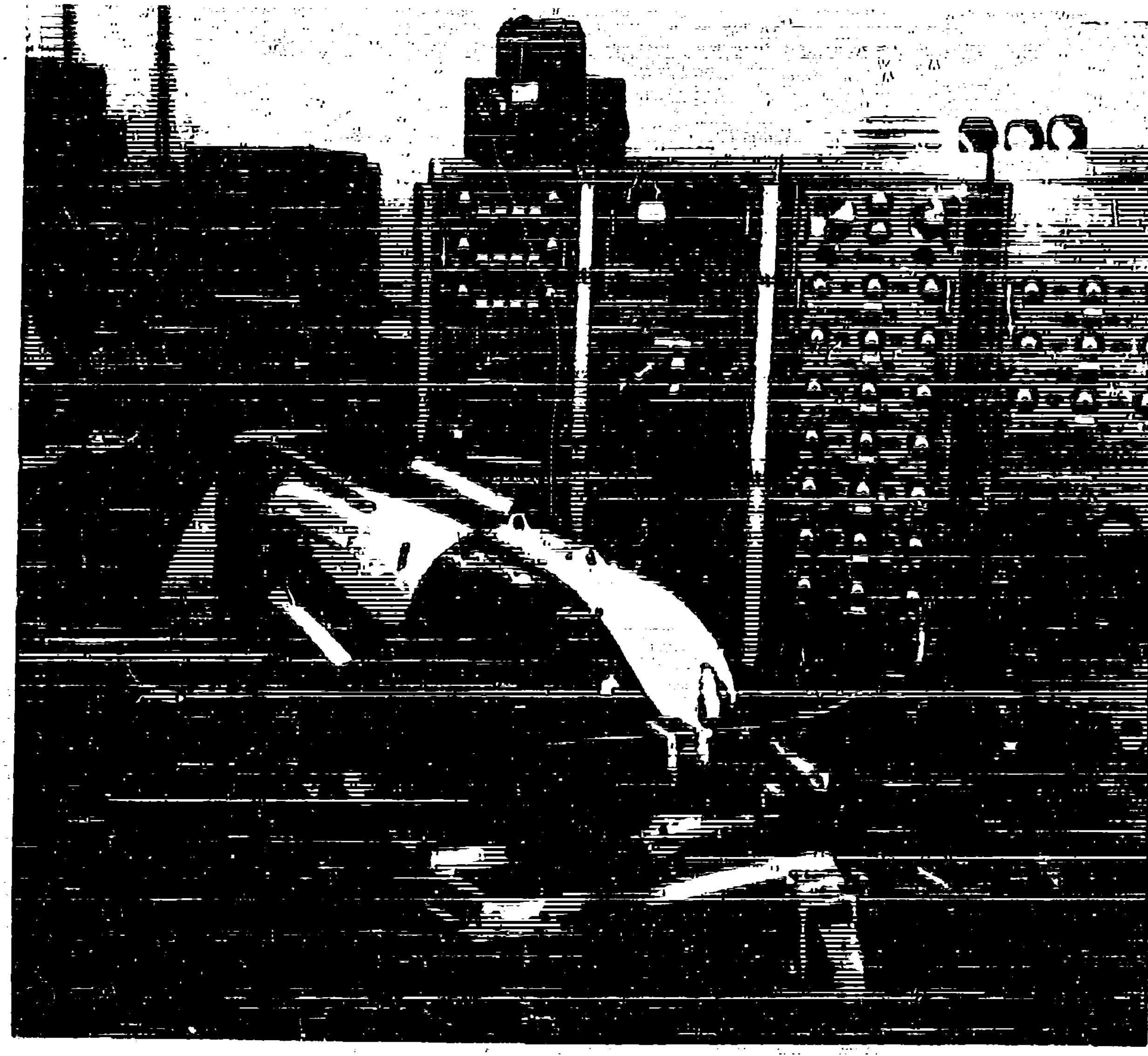


Figure 8-1-26. Telemetering Installation on Test Vehicle

into terms of the original quantity for purpose of analysis.

The accuracy of telemotored data is dependent upon proper shockmounting, vibration isolation, temperature control and compensation, voltage control, and calibration.

The continuous reading type is limited to 18 bands by the RDB specification. In general, one intelligence signal is assigned to each different subcarrier frequency band. The individual sensed datum is used to frequency-modulate a subcarrier oscillator within the limits of its assigned band of frequencies.

It has been shown that only a limited number of single intelligence channels may be combined in a multiple technique to accommodate a number of different measurements simultaneously. If, however, the intelligence sources may be sampled in a recurring sequence, the number of channels that may be recorded is very large. Each band, or a number of bands, may carry as many as 27 different intelligence data per band by utilizing a commutator switch. This sampling is, however, accompanied by a substantial reduction in the rate of intelligence changes (frequency response) that can be accurately transmitted. A number of telemetering sys-

tems are commercially available, and detailed performance data may be obtained from manufacturers' catalogs.

1.2.5 LABORATORY INSTRUMENT SYSTEMS.

1.2.5.1 Static and Dynamic Strain Recording System. (See Figure 8-1-27.) The static and dynamic strain recording system is widely used for recording test information in wind tunnel tests and other static test facilities, such as platform test facilities. This system consists of a carrier system to measure and record phenomena in the range of 0 to 600 cps, utilizing variable resistance type or variable reluctance type pickups as sensing elements, a power unit to supply the carrier system with the voltages required, and a light-beam oscillograph. The entire system is miniaturized and ruggedized especially for mobile and aircraft use. Physically, the system is composed of two or three units on shock mounts. One case contains the power supply, the other contains the amplifiers, and the third is the light-beam oscillograph itself. A variety of static and dynamic strain recording systems are commercially available, and detailed performance data may be obtained from manufacturers' catalogs.

1.2.5.2 Magnetic Tape Playback System. (See Figure 8-1-28.) The magnetic tape playback system converts the frequency-modulated signals recorded previously on magnetic tape into analog voltages through discriminator action. The recording is a frequency-modulated signal, with a full-scale swing of 600 cycles about a signal frequency of 3.5 kilocycles. The tape transport mechanism drives the tape past a pickup head. First, the signal picked up from this head is passed through a preamplifier. After further amplification, the signal is clipped and shaped into pulses suitable for triggering a mono-stable-multi-vibrator type pulse rate counter. The resulting pulses are passed to a low-pass filter circuit, which has a cutoff frequency of 200 cps. The d-c voltages at the filter output are then sent to

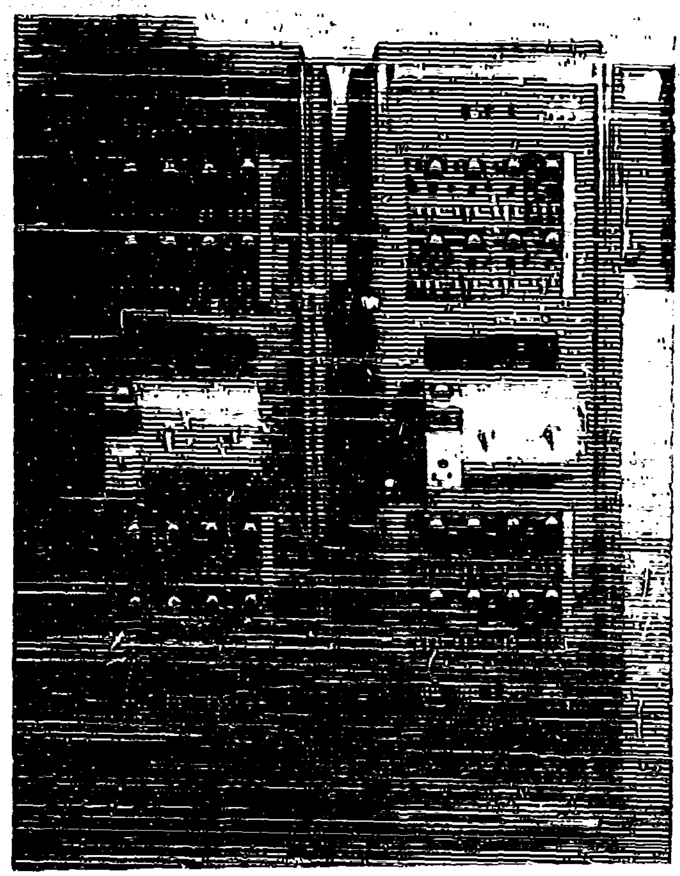


Figure 8-1-27. Static and Dynamic Strain Recording Systems

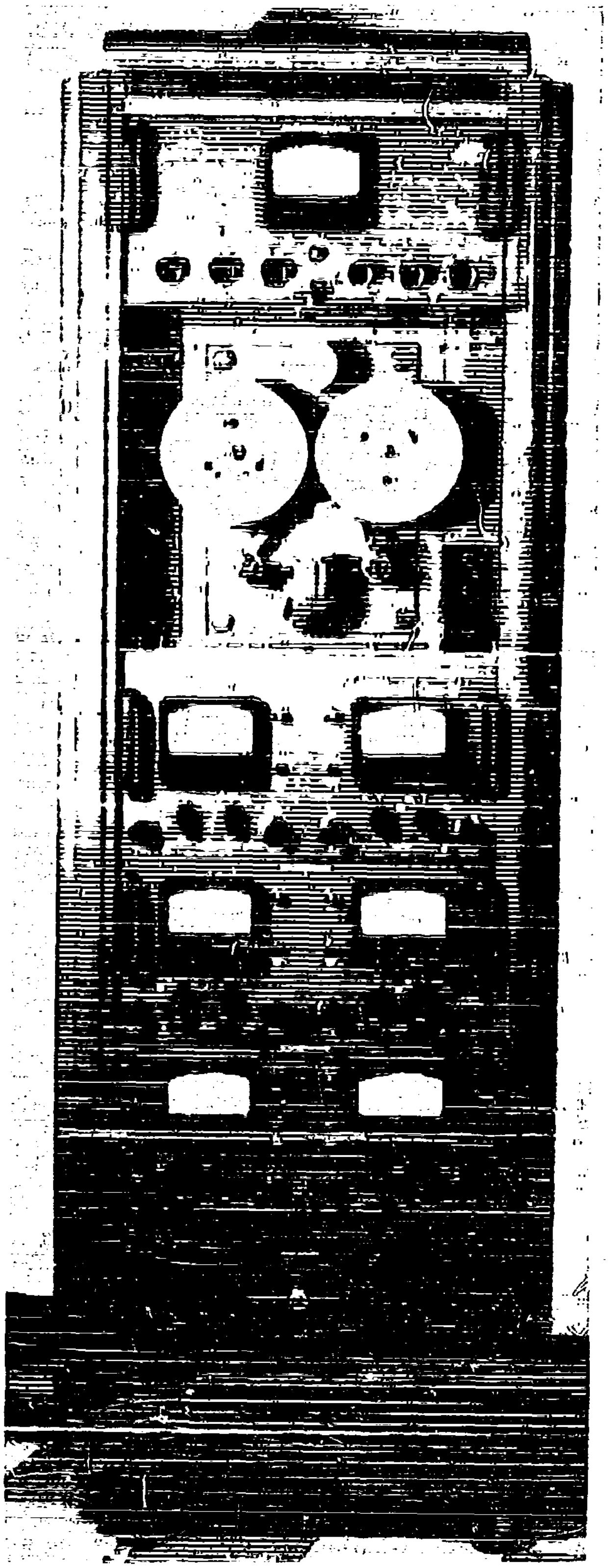


Figure 8-1-28. Magnetic Tape Playback System

an amplifier, which furnishes the power amplification necessary to drive a galvometer or light-beam oscillograph. Since the speed of recording of recording may not be constant, playback at constant speed would not result in faithful data reproduction. Therefore, a variable speed tape transport is used for playback. This tape transport receives its control signal from the reference frequency channel on the recorded tape. A 4,000-cps fixed frequency is recorded on this channel. Tape flutter and wow appear as a frequency modulation of the 4,000-cps carrier frequency. This signal is detected in a manner similar to that used in the data discriminator. The signal is amplified and used to control the capstan drive speed, where it removes the long-term speed variation problem. The large inertia of the system prevents instantaneous action. Therefore, this reference signal is also used to control the bias on the pulse height limiting diode of the data discriminator circuits. The result is a cancellation of the noise at the output of the data discriminator. The result of this action is a faithful analog reproduction of the digital input data. The six-channel playback system is completely contained in a 70-inch relay rack cabinet. This relay rack cabinet houses the playback tape mechanism, calibration oscillometer, reference reconverter, preamplifier, motor control, and six data reconverters. The complete system is powered from a 150-volt line through a solar regulating transformer. The tape drive mechanism is powered by d-c motors for the capstan drive and the tape-up spool. The unit is designed for two-speed operation. The nominal tape speeds in the playback operation are approximately 11 and 30 inches per second. The unit will accommodate either 1/2- or 1-inch wide tape. Auxiliary equipment for this magnetic tape playback system consists of either a six-channel direct writing recorder or a six-channel light-beam oscillograph, which converts the output signals of the data reconvertors into permanent records.

1.2.5.3 Three-Component Balance, Mechanical and Electrical. (See Figure 8-1-29.) This balance was designed and constructed for the purpose of measuring drag, lift, and moments on parachutes or parachute-vehicle combinations in a wind tunnel. The three-component balance is a precision instrument capable of very accurate measurement of forces and moments on a test vehicle or parachute in an air stream. The load capacity of the balance is as follows: Drag — ± 60 lb.
Lift — ± 15 lb.
Moment — ± 12 ft. -lb.

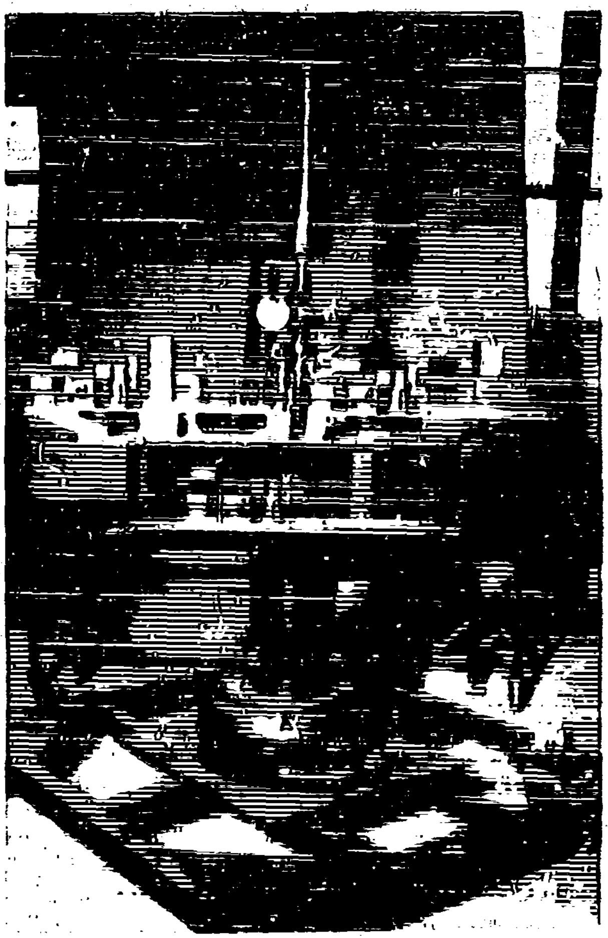


Figure 8-1-29. Three-Component Balance

The measuring system is based upon the following principle: The test vehicle or parachute is suspended on a support rod that terminates in a universal joint located in the base of the support stand. The support rod is therefore movable around the pivot point in the universal joint, with a minimum of friction in all directions. The lower half of the universal joint terminates in a shaft, which is held in position by ball bearings that allow free rotation of the model support assembly. A single ball-bearing bracket is mounted at exactly half the length of the supporting rod and serves for the purpose of transferring the load to the linkage system of the individual scales. The linkage systems, in turn, transfer the forces to the poise weight scales. A counter indicates the position of the scale poise weight and therefore allows an accurate reading of the forces acting on the test vehicle or parachute. Provisions are made either for simultaneous measurement of all components or for "freezing" of each individual component. Strain gage flexures are installed in the linkage system of each balance in order to allow for combined mechanical or electrical measurement.

1.2.6 *ASSOCIATED EQUIPMENT.*

1.2.6.1 550 - Pound Cord with Transmission Leads. A 550-pound nylon cord with four insulated transmission leads is used as suspension line to canopies on which pressure or stress phenomena are intended to be measured. Of primary importance during such tests is the maintenance of constant transmission lead resistance at all times. Because of the stretch in suspension lines under canopy loads, it is necessary that the outer braids, which include the transmission lines, carry none of the load of the canopy with an elongation of up to 30 percent. This is accomplished by using a building angle, which assures that when the suspension line is stretched the decrease in diameter of the transmission line holding braid is less than that of the central nylon core; consequently, it becomes slightly loose and no stresses are placed on the outer braid. The type now in use has only a 1.26 percent increase in resistance at 30 percent elongation and a 0.61 percent increase at 25 percent elongation.

1.2.7 PHOTOTHEODOLITE (CINETHEODOLITE). (See Figure 8-1-30.) Phototheodolites are used to record on film a complete record of parachute and/or vehicle behavior. Each instrument consists of an optical system embodying powerful lenses for tracking and photographing the object being monitored. The cameras not only photograph the object but also record time, azimuth, and elevation. Photos are taken at the rate of 10 per second. Tracking is accomplished by hand cranking. Normally, three instruments are used and are so placed that their respective angles of elevations and azimuths, taken at any specific time, pinpoint with extreme accuracy the position of the monitored object. Data reduction is accomplished by IBM computers from the information afforded by the film. The phototheodolite excels in accuracy of trajectory, speed, rate of descent, and drift measurements. Figure 8-1-30 shows the distance an object may be tracked under good visibility conditions.

1.2.8 PHOTOGRAPHIC CAMERAS. For the purpose of obtaining photographic coverage of the parachute deployment sequence, flying shape, and other characteristics during drop

tests, cameras are installed in drop test vehicles. In general, G.S.A.P. cameras are used, modified for a film speed of up to 100 frames per second and equipped with wide-angle lenses (17-mm.). If high-speed movies are required, Bell and Howell or Fastax cameras are used.

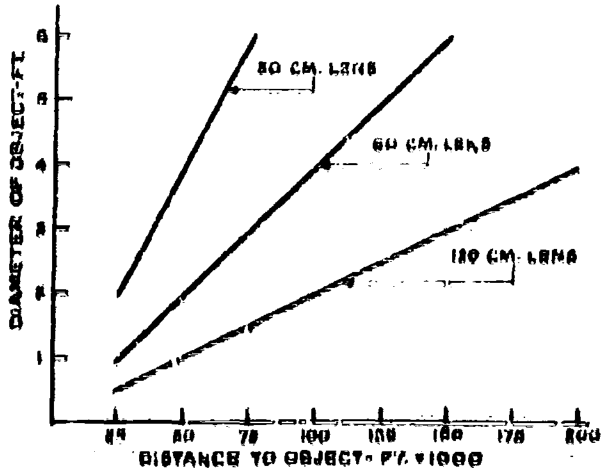


Figure 8-1-30. Theodolite — Diameter of Object Versus Maximum Tracking Distance

CHAPTER VIII

SECTION 2

TEST METHODS

2.1 GENERAL.

Before any test program is initiated, a careful analysis of the full objective of the program must be made. Such an analysis can determine such things as:

a. Scope of test program.
b. Desirability of using model parachutes.
c. Test equipment needed.
d. Necessary local manufacture or alteration needed on test equipment.
e. Test results anticipated.
f. Desired instrumentation.
g. Requirement for alteration of the equipment being tested during course of tests.

From the information thus gained, a program including the following is made out.

Description of item to be tested:

Parachute(s) and Accessories

a. Standard types
b. Test types
c. Special types

Special Supporting Equipment

a. Transportation
b. Cranes
c. Trucks, radio jeep, etc.

Photographic Requirements

a. Air-to-air
b. Ground-to-air
c. Aircraft-to-aircraft
d. Bombs-to-air
e. Special vehicles

Test Equipment Needed (bombs, platforms, etc.):

Test Performance Ranges

a. Launching speed
b. Launching altitude
c. Total drop weight

Aircraft Requirements

a. Drop aircraft type
b. Support aircraft type
c. Special purpose aircraft type

Other Test Facilities

a. Whirl tower
b. Paragun
c. Wind tunnel
d. Static test facilities
e. Aircraft tow

Instrumentation Requirements

a. Telemetering
b. Magnetic tape recorder
c. Tensiometer, self-recording
d. Accelerometer, self-recording
e. Oscillometer, self-recording
f. Sensing Elements
g. Dropline
h. Phototheodolite
i. Other

2.2 PARACHUTE TESTING METHODS.

2.2.1 GENERAL. The methods of testing which have been and are being employed in the evaluation of parachute and parachute systems characteristics and performance may be classified as follows:

a. Drop tests
   (1) from aircraft
   (2) in inclosed shelter
b. Wind tunnel tests
c. Laboratory tests
d. Whirl tower tests
e. Aircraft tow tests
f. Projectile gun tests
g. Rocket sled tests
h. Impact testing on inclined test facility for heavy cargo equipment

Each of these tests has its own particular advantages. In some instances, the only worthwhile test will be actual aircraft drop tests.

In many other instances, use of other types of tests will reflect great savings in cost, much more rapid programming, more accurate and complete instrumentation, better photographic coverage, and more precise test control. Possible utilization of available test facilities and instrumentation is compiled in Figure 8-2-1. This tabulation is based upon results obtained during parachute test application; however, it does not limit the utilization of either test facilities or instrumentation to those listed, nor does it restrict possible combinations of both.

2.3 DROP TESTS.

2.3.1 GENERAL. The great majority of parachute drop tests are performed by one of two basic methods:

a. from a fixed position in the air or in an enclosed shelter
b. from an aircraft in flight.

The greatest single advantage of the free-fall drop method is the absence of any restraint on the motion of the parachute-load system. Because the control and measurement of test conditions, as well as observation of the motion of the parachute system, are difficult in free air, the sheltered parachute drop tests have been the most productive of accurate quantitative data. In general, airshop docks and parachute drying towers are used for indoor tests on small-size canopies.

2.3.2 DROP TESTS IN ENCLOSED SHELTERS. (See Figure 8-2-2.) A number of parachute test programs have been conducted in enclosed shelters, and accurate performance characteristics have been obtained. During these test programs, model parachutes in sizes of up to 12 feet in diameter were used and performance data, such as drag coefficient, oscillation (amplitude and frequency), opening shock, and drift, have been obtained.

2.3.3 USE OF MODEL PARACHUTES. Model parachutes provide a relatively inexpensive means of determining trends in parachute design. Model parachutes do not have the same drag coefficients as their full-size counterparts. However, any change in a model parachute that shows a drag coefficient change will generally achieve a change in the same direction on a larger chute that is so modified. The same holds true for design changes affecting stability and to a certain degree, opening characteristics.

2.3.4 SIXTY-FOOT DROP TOWER. (See Figure 8-2-3.) A 60-foot outdoor tower is used to simulate the forces encountered in certain cases in which acceleration and deceleration measurements are desired. Full telemetering magnetic tape recording, or direct recording, is available at the site. It can only be used for load drops within weight limitations; it cannot be used to test canopies. It may be used to test dynamic stresses in parachute harness and risers.

2.3.5 CRANE OR HOIST DROP TEST. Cranes or hoists provide an economical method of making static drop tests. They are particularly valuable in testing impact reaction. The object under test may be hoisted to a height which will achieve an impact velocity equal to the desired rate of descent. Figure 8-2-4 shows a cargo platform system undergoing an impact test. In such tests, platform decelerations and pressures within the air bags may be measured, and moving pictures will record platform behavior during ground impact. One disadvantage of this type of test is that terrain and drift conditions may not duplicate actual drop.

2.3.6 DROP TESTS FROM AN AIRCRAFT IN FLIGHT. (See Figure 8-2-5.) Drop tests from aircraft have the advantage of obtaining actual full-scale conditions at speeds and altitudes up to about 430 knots at 40,000 feet. Two general types of tests are performed: functional tests and performance tests. The purpose of the functional drop test is to determine whether a parachute design or parachute system will behave as predicted when subjected to a known set of conditions. The performance test is made for the purpose of evaluating the various mechanical and aerodynamic characteristics of a parachute design or parachute system. The following information may be obtained during these tests: (1) deployment sequence time, (2) inflation time, (3) opening shock and force time history, (4) average drag coefficient, (5) stability (average angle and frequency of oscillation), (6) gliding (average flight angle and path), (7) flight trajectory and rate of descent, (8) strength, and (9) flying shapes.

During these drop tests, aside from describing the parachute system, instrumentation, drop test vehicle type, and weight used during the test, the following vital data should be recorded to assure the usefulness and generality of reported drop test results and allow for their close evaluation: (1) launching velocity, (2) launching altitude, (3) static line lengths, (4) timer used, (5) deployment time, (6) opening time, (7) filling time, (8) reefing time, (9) disreefing time, (10) extent of damage, (11) rate of descent, (12) drift, (13) oscillation

TEST METHOD	DRAG COEFFICIENT	SNATCH FORCE	OPENING SHOCK	STABILITY	CANOPY OPENING TIME	FORCES IN HARNESS, RISER AND [illegible]	FORCES, PRESSURES IN CANOPY	FORCES IN REEFING SYSTEMS	GROUND IMPACT	RELIABILITY	DE[illegible]TION	KEY (SEE FIG. 8-2-1B)
DROP TESTS FROM AIRCRAFT	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	GOOD-COMPLICATED INSTALLATION	GOOD-COMPLICATED INSTALLATION	GOOD	EXCELLENT	EXCELLENT NOT VERY ECONOMICAL	EXCELLENT NOT VERY ECONOMICAL	1
WIND-TUNNEL	EXCELLENT	GOOD	GOOD	GOOD-BUT MAY NOT SUPPLY TRUE VALUES FOR APPLICATION	GOOD	N/A	EXCELLENT	EXCELLENT	N/A	GOOD WITHIN LIMITATIONS	N/A	2
DROP TESTS IN ENCLOSED SHELTERS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	LIMITED APPLICATION	LIMITED APPLICATION	N/A	N/A	N/A	N/A	N/A	N/A	3
60' FREE-FALL DROP TOWER	N/A	N/A	N/A	N/A	N/A	EXCELLENT	N/A	N/A	EXCELLENT FOR LANDING SHOCK ABSORBING SYSTEMS	EXCELLENT FOR LANDING SHOCK ABSORBING SYSTEMS	EXCELLENT FOR LANDING SHOCK ABSORBING SYSTEMS	4
DROP TESTS FROM CRANE OR HOIST	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	GOOD FOR PLATFORMS, CONTAINERS, SHOCK ABSORBER	GOOD FOR PLATFORMS, CONTAINERS, SHOCK ABSORBER	GOOD FOR PLATFORMS, CONTAINERS, SHOCK ABSORBER	5
PARACHUTE WHIRL TOWER	N/A FREE-FALL DISTANCE TOO SHORT	EXCELLENT	EXCELLENT	N/A	EXCELLENT	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD	N/A	EXCELLENT	EXCELLENT	6
AIRCRAFT TAXI-TOW TESTS	GOOD FOR DECELERATION CHUTE TESTS FOR SIMILAR APPLICATIONS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD FOR SIMILAR APPLICATIONS	GOOD	EXCELLENT	EXCELLENT	N/A	LIMITED TO DECE[illegible] PARACHUTE SYSTEMS	LIMITED TO DECELERATION PARACHUTE SYSTEMS	7
AIRCRAFT IN-FLIGHT TOW TESTS	GOOD FOR SIMILAR APPLICATIONS	GOOD FOR INFINITE MASS CONDITIONS	GOOD FOR INFINITE MASS CONDITIONS	GOOD FOR SIMILAR APPLICATIONS	GOOD FOR SIMILAR APPLICATIONS	GOOD	EXCELLENT	EXCELLENT	N/A	FAIR FOR CONTINUOUS HIGH SPEED TESTS	EXCELLENT	8
PROJECTILE GUN TESTS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD WITHIN LIMITATIONS	GOOD	N/A	N/A	N/A	N/A	FAIR FOR CONTINUOUS HIGH SPEED TESTS	EXCELLENT	9
ROCKET SLED TESTS	EXCELLENT	EXCELLENT	EXCELLENT	GOOD WITHIN LIMITATIONS	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	N/A	N/A	N/A	10
INCLINED TEST FACILITY FOR SIMULATING LANDING COND. OF HEAVY EQUIP.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	EXCELLENT	EXCELLENT FOR PLATFORMS, CONTAINERS, SHOCK ABSORBING SYSTEMS	EXCELLENT FOR PLATFORMS, CONTAINERS, SHOCK ABSORBING SYSTEMS	11

Figure 8-2-1A. Test Facilities

		Drag Coefficient – Exploratory	Drag Coefficient – Engineering	Canopy Force – Exploratory	Canopy Force – Engineering	Opening Shock – Exploratory	Opening Shock – Engineering	Stability – Exploratory	Stability – Engineering	Canopy Opening Time – Exploratory	Canopy Opening Time – Engineering	Forces in [illegible] – Exploratory	Forces in [illegible] – Engineering	Forces Transmitted to Canopy – Exploratory	Forces Transmitted to Canopy – Engineering	Forces in Deploying System – Exploratory	Forces in Deploying System – Engineering	Ground Impact – Exploratory	Ground Impact – Engineering	Reliability	Destruction
CANOPY DEVELOPMENT SIZE - UP TO 8' DIA.	TEST METHOD	1 2 3	1 2	1 2	1 2	1 2	1 2	1 2 3	1 2	1 2 3	1 2	2	2	2	2	2	2	NOT APPLICABLE		1 2 3 6	1 6
	INSTRUMENTATION	T G S	D F U	A B U	A B U	A B U	A B U	G U S	S F U	U S U	T J F	U	U	U	U	U	U			A U S A	A A
CANOPY DEVELOPMENT SIZE - UP TO 16' DIA.	TEST METHOD	1	1	1 6	1 6	1 6	1 6	1	1	1 6	1 6	1 6	1 6	2	1 6	3	1 6	NOT APPLICABLE		1 6	1 6
	INSTRUMENTATION	T	D F	A B A B	D I	A B A B	D I	C	C V	S S	S Y F	T J D J	D J I J	U	P O S	U	D I D I			A A	A A
CANOPY DEVELOPMENT SIZE - UP TO 30' DIA.	TEST METHOD	1	1	1 6 1 6	1 6	1 6 1 6		1	1	1 6	1 6	1 6	1 6	6	1	1 6	1 6	NOT APPLICABLE		1 6	1 6
	INSTRUMENTATION	T	I K V	A B A B	A D I	A B A B	A D I	C	C V	S S	S Y F	D I D J	D J D J	F K G L	F K G L	U D I	D I J			A A	A A
CANOPY DEVELOPMENT SIZE - LARGER THAN 30' DIA.	TEST METHOD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	NOT APPLICABLE		1	1
	INSTRUMENTATION	T	I K V	A B	A I	A B	A I	C	C M G V	S	S Y	I	I	F K G L	F K G L	I	I			A B	A B
PERSONNEL PARACHUTE SYSTEMS	TEST METHOD	1	1	1 6	1	1 6	1	1	1	1 6	1	1 6 6	1 6	NOT APPLICABLE		NOT APPLICABLE		1 9	1	1 6	1 6
	INSTRUMENTATION	T	I K V	A A	A	A A	A	C	C V	S S	S Y	D I D J	D J D J					B J B U	B E J	A A	A A
CARGO PARACHUTE SYSTEMS LOAD EXTRACTION PARACHUTE	TEST METHOD	1	1	1	1	1	1	1	1	1	1	1	1	NOT APPLICABLE		1	1	NOT APPLICABLE		1	1
	INSTRUMENTATION	K P	I K	A	I M	A	I M	S	S	I	I	M	I			M	I			A I N	A I N
CARGO PARACHUTE SYSTEMS DESCENT PARACHUTE	TEST METHOD	1	1	1	1	1	1	1	1	1	1	1	1	NOT APPLICABLE		1	1	NOT APPLICABLE		1	1
	INSTRUMENTATION	T	I K V	A	A I	A	A I	C	C V	S	S Y	I	I			I	I			A B	A B
CARGO PARACHUTE SYSTEMS PLATFORMS, CONTAINERS, LANDING SHOCK ABSORBING DEVICES	TEST METHOD	NOT APPLICABLE		NOT APPLICABLE		NOT APPLICABLE		NOT APPLICABLE		NOT APPLICABLE		1 4	1 1	NOT APPLICABLE		NOT APPLICABLE		11	1	1 11	11
	INSTRUMENTATION											I U	I U					B U	B J	B J U	B U
RECOVERY PARACHUTE SYSTEMS DECELERATION STAGES	TEST METHOD	1 10	1 10	1 10	1 10	1 10	1 10	1 10	1 10	1 10	1 10	1 10	1 10	NOT APPLICABLE		1 10	1 10	NOT APPLICABLE		1 10	1 10
	INSTRUMENTATION	D F T	I K V	A B D F	A I	A B D F	A I	C N	C M G V	S S	S Y	D I	D I			D I	D I			D I I	A B I
RECOVERY PARACHUTE SYSTEMS FINAL STAGE RECOVERY	TEST METHOD	1	1	1	1	1	1	1	1	1	1	1	1	NOT APPLICABLE		1	1	NOT APPLICABLE		1	1
	INSTRUMENTATION	D F T	D I F K V	A D B I	A D B I	A D B I	A D B I	C N	C M G V	S	S Y	D I	D I			D I	D I			A D I	A B
RECOVERY PARACHUTE SYSTEMS COMPLETE SYSTEMS TEST	TEST METHOD	1	1	1	1	1	1	1	1	1	1	1	1	NOT APPLICABLE		1	1	1	1	1	1
	INSTRUMENTATION	D F	D I F K V	A D B I	A D B I	A D B I	A D B I	C N	C M G V	S	S Y	D I	D I			D I	D I	B E J	B E J	D I S	A B
STABILIZATION PARACHUTE SYSTEMS	TEST METHOD	1 2	1 10	1 2	1 10	1 2	1 10	1 2	1 10	1 2	1 10	1 2	1 10	NOT APPLICABLE		1 2	1 10	1	1	1 2 10	1 10
	INSTRUMENTATION	D F U	D F I K	A B D G	A B G U	A B G U	A B G U	C S	C M G U	S S	S Y I	D I	D I			D I J	D I J	B E J	B E J	D I U I	A B I
AIRCRAFT IN-FLIGHT DECELERATION PARACHUTE SYSTEMS	TEST METHOD	1	8	1	8	1	8	1	8	1	8	1	8	8	8	1 8	8	NOT APPLICABLE		1 8	1 8
	INSTRUMENTATION	T	M P	A B	N	A B	N	C	M S	S Y	S	D I	N	P Q	P Q	D I N	N			A N	A N
AIRCRAFT LANDING DECELERATION PARACHUTE SYSTEMS	TEST METHOD	1	7	1	7	1	7	1	7	1	7	1	7	7	7	7	7	NOT APPLICABLE		1 7	1 7
	INSTRUMENTATION	T	M P	A B	N	A B	N	C	M S	S Y	S	D I	N	P Q	P Q	N	N			A N	A N

KEY

PARACHUTE TEST METHODS:

1 - DROP TESTS FROM AIRCRAFT
2 - WIND TUNNEL
3 - DROP TESTS IN ENCLOSED SHELTERS
4 - 60' FREE FALL DROP TOWER
5 - DROP TESTS FROM CRANE OR HOIST
6 - PARACHUTE WHIRL TOWER
7 - AIRCRAFT TAXI-TOW TESTS
8 - AIRCRAFT IN-FLIGHT TOW TESTS
9 - PROJECTILE GUN TESTS
10 - ROCKET SLED TESTS
11 - INCLINED TEST FACILITY

PARACHUTE TEST INSTRUMENTATION:

SELF RECORDING
A - TENSIOMETER
B - ACCELEROMETER
C - OSCILLOMETER
TELEMETERING WITH
D - TENSIOMETER
E - ACCELEROMETER
F - PRESSURE TRANSDUCER
G - EXTENSIOMETER
H - POSITION INDICATOR
TAPE RECORDING WITH
I - TENSIOMETER
J - ACCELEROMETER
K - PRESSURE TRANSDUCER
L - EXTENSIOMETER
M - POSITION INDICATOR
LIGHT-BEAM OSCILLOGRAPH WITH
N - TENSIOMETER
O - ACCELEROMETER
P - PRESSURE TRANSDUCER
Q - EXTENSIOMETER
R - POSITION INDICATOR
S - TIMED MOTION PICTURES
T - DROP LINE
U - STRAIN RECORDING SYSTEM
V - CINE THEODOLITE

Figure 8-2-1D. Suggested Test Facilities and Instrumentation Utilization

TEST	GROUND-STATIONED INSTRUMENTS (STATIC TESTS)		INSTRUMENTS FOR AIRBORNE APPLICATIONS																				
					LIGHT-BEAM OSCILLOGRAPH WITH					MAGNETIC TAPE RECORDING WITH					TELEMETERING SYSTEM WITH					SELF-RECORDING		
	CINE THEODOLITE	STRAIN RECORDING SYSTEM	DROP LINE	TIMED MOTION PICTURES	POSITION INDICATOR	EXTENSIOMETER	PRESSURE TRANSDUCER	ACCELEROMETER	TENSIOMETER	POSITION INDICATOR	EXTENSIOMETER	PRESSURE TRANSDUCER	ACCELEROMETER	TENSIOMETER	POSITION INDICATOR	EXTENSIOMETER	PRESSURE TRANSDUCER	ACCELEROMETER	TENSIOMETER	OSCILLOMETER	ACCELEROMETER	TENSIOMETER
DRAG COEFFICIENT	GOOD	EXCELLENT FOR STATIC TESTS	GOOD (INEXPENSIVE)	N/A	N/A	N/A	GOOD FOR RATE OF DESCENT	FAIR	EXCELLENT FOR DRAG MEASUREMENT	N/A	N/A	GOOD FOR RATE OF DESCENT	FAIR	EXCELLENT FOR DRAG MEASUREMENT	N/A	N/A	GOOD FOR RATE OF DESCENT	FAIR	EXCELLENT FOR DRAG MEASUREMENT	N/A	FAIR	EXCELLENT FOR DRAG MEASUREMENT
SNATCH FORCE	N/A	EXCELLENT FOR STATIC TESTS	N/A	N/A	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	GOOD	EXCELLENT
OPENING SHOCK	POSSIBLE	EXCELLENT FOR STATIC TESTS	N/A	N/A	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	N/A	N/A	GOOD	EXCELLENT	N/A	GOOD	EXCELLENT
STABILITY	GOOD	EXCELLENT FOR STATIC TESTS	N/A	EXCELLENT	EXCELLENT	N/A	N/A	FAIR	N/A	EXCELLENT	N/A	N/A	FAIR	N/A	EXCELLENT	N/A	N/A	FAIR	N/A	EXCELLENT	FAIR	N/A
CANOPY OPENING TIME	GOOD	N/A	N/A	EXCELLENT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FORCES IN HARNESS, RISER, WEBBING	N/A	EXCELLENT FOR STATIC TESTS	N/A	N/A	N/A	GOOD	N/A	N/A	EXCELLENT	N/A	GOOD	N/A	N/A	EXCELLENT	N/A	GOOD	N/A	N/A	EXCELLENT	N/A	N/A	GOOD
FORCES, PRESSURES IN CANOPY	N/A	EXCELLENT FOR STATIC TESTS	N/A	EXCELLENT FOR CANOPY SHAPE	N/A	EXCELLENT (MINIATURIZED)	EXCELLENT (MINIATURIZED)	N/A	N/A	N/A	EXCELLENT (MINIATURIZED)	EXCELLENT (MINIATURIZED)	N/A	N/A	N/A	EXCELLENT (MINIATURIZED)	EXCELLENT (MINIATURIZED)	N/A	N/A	N/A	N/A	N/A
FORCES IN REEFING SYSTEMS	N/A	EXCELLENT FOR STATIC TESTS	N/A	N/A	N/A	FAIR	N/A	N/A	EXCELLENT	N/A	FAIR	N/A	N/A	EXCELLENT	N/A	FAIR	N/A	N/A	EXCELLENT	N/A	N/A	FAIR
GROUND IMPACT	N/A	EXCELLENT FOR STATIC TESTS	N/A	GOOD	N/A	N/A	POSSIBLE FOR SHOCK ABSORBING SYSTEMS	POSSIBLE	N/A	N/A	N/A	EXCELLENT FOR SHOCK ABSORBING SYSTEMS	EXCELLENT	N/A	N/A	N/A	EXCELLENT FOR SHOCK ABSORBING SYSTEMS	EXCELLENT	N/A	N/A	EXCELLENT	N/A
RELIABILITY	N/A	N/A	N/A	GOOD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	GOOD FOR STABILITY DETERMINATION	N/A	N/A
DESTRUCTION	N/A	N/A	N/A	GOOD	N/A	N/A	N/A	POSSIBLE	FAIR	N/A	N/A	N/A	EXCELLENT WITH RECOVERY PROVISIONS	EXCELLENT WITH RECOVERY PROVISIONS	N/A	N/A	N/A	EXCELLENT WITH RECOVERY PROVISIONS	EXCELLENT WITH RECOVERY PROVISIONS	N/A	EXCELLENT	EXCELLENT
KEY (SEE FIG 8-2-1B)	V	U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A

Figure 8-2-1C. Instrumentation

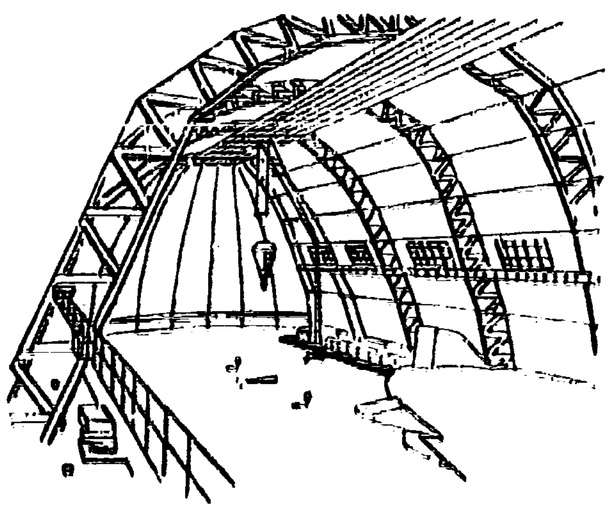


Figure 8-2-5. Drop Test in Large Airship Dock

angle and frequency, (14) general impression of parachute behavior, (15) wind velocity, (16) air temperature, (17) barometric pressure, (18) relative humidity, (19) general atmospheric conditions (visibility, etc.), and (20) type of terrain. For special high-altitude tests the knowledge of the position of the sun may be of value.

2.4 WIND TUNNEL TESTS.

2.4.1 ADVANTAGES. The use of wind tunnels for the measurement of aerodynamic characteristics and the acquisition of performance data applicable to parachute design has been one of the most productive testing methods for the advancement of parachute designs. (See Figure 8-2-6.) Although wind tunnel testing is not well adapted to the study and determination of all of the aerodynamic characteristics of parachutes and parachute systems, the method presents certain advantages that balance out the shortcomings of data obtained. The advantages of the wind tunnel method relative to other parachute test methods derive mainly from the following considerations: (1) the test conditions are subject to close control, (2) measurement of maximum precision may be made, (3) many test data can be obtained in a short period of time, and (4) comparative relationships usually carry over to full scale fr[illegible]onditions, within certain limits.

2.4.2 DISADVANTAGES. Disadvantages arise mainly from the small models required, the restraint placed on the freedom of motion of the system in the wind tunnel, and limitations placed on the maximum dynamic pressures that can be applied. A number of test problems are encountered during wind tunnel tests, of which the most important are: (1) wind tunnel wall and blocking effect, (2) testing below the critical Reynolds number, (3) direct measurement of canopy side loads, and (4) mounting of the models to minimize separation effects.

Blocking effects arise when the ratio of the model diameter to the throat diameter is large. The maximum ratio of model diameter to wind tunnel jet diameter is in the order of 12 to 25 percent if blocking effects are to be minimized. This diameter ratio applies to shock force measurement only, and not to forces and moments acting on the canopy, where smaller models should be used. In general, for best results, the projected area of the inflated canopy should not exceed 15 percent of the tunnel throat area.

Wind tunnel tests are conducted above the critical Reynolds number, whenever possible, in order to minimize scale effect. As in aircraft work, an attempt is made to achieve Reynolds numbers equivalent to actual full-scale test conditions, but this has seldom been feasible, because of the large size of the parachutes.

The system for mounting the model in the wind tunnel should be sufficiently rigid to prevent vibration from causing excessive fluctuation in the angle of attack.

2.4.3 PERFORMANCE CHARACTERISTICS. The following parachute performance characteristics may be determined in a wind tunnel:

a. Aerodynamic force and moment coefficient versus angle of attack.
b. Geometrical properties of the inflated canopy.
c. Critical opening and closing velocities.
d. Dynamic stability of missile stabilizing systems.
e. Opening shock and other inflation characteristics.
f. Rotational velocity of autorotating parachutes.
g. Force and inflation characteristics of reefed parachutes.
h. Other pertinent data.

2.5 LABORATORY TESTS.

2.5.1 GENERAL. Laboratory tests include tests made on the component part rather than on the

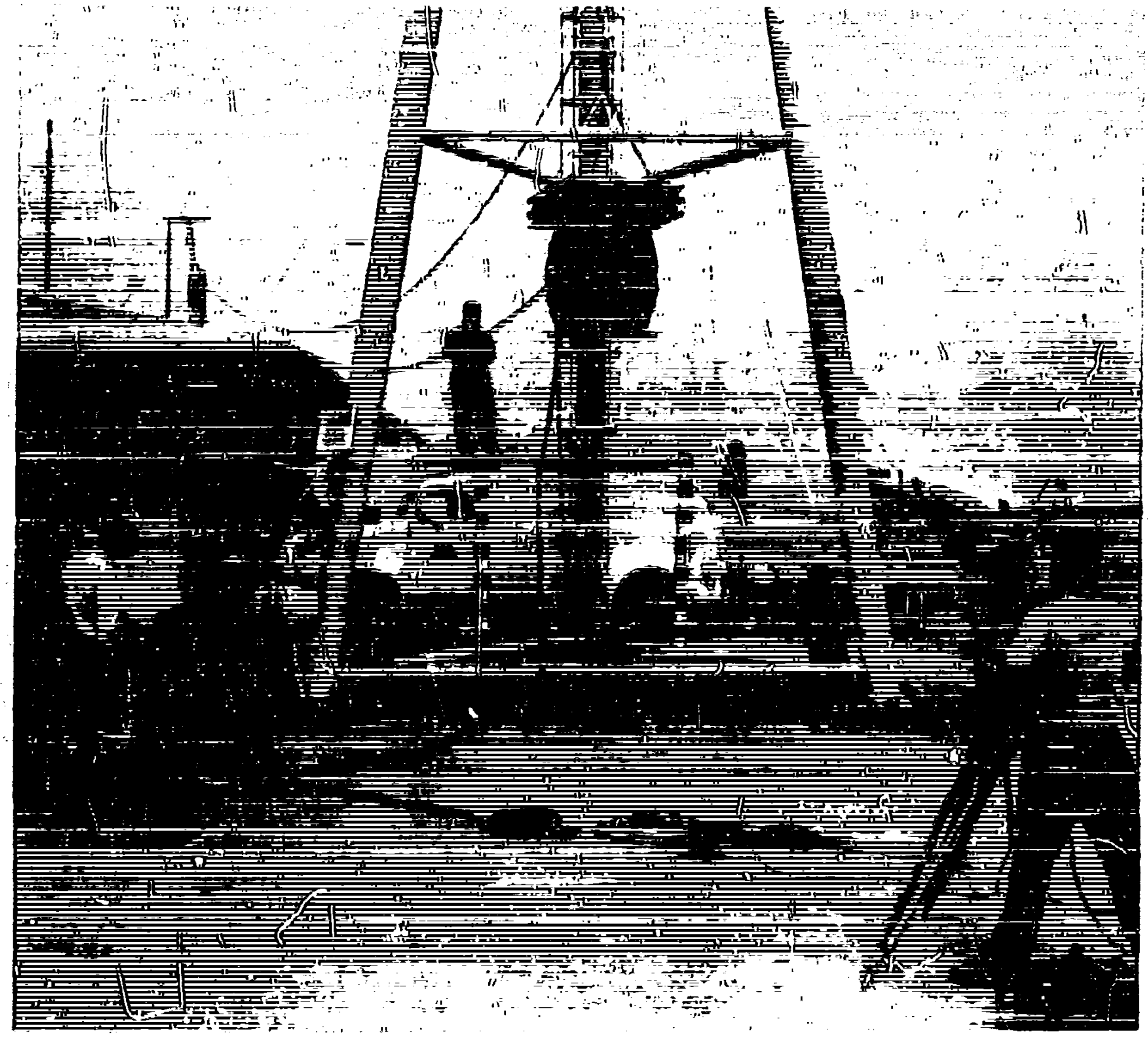


Figure 8-2-3. Air Bag Undergoing Test Using 60-Foot Drop Test Facility

complete parachute assembly. The primary area of investigation on fabrics involves permeability, strength, and elasticity. Subsidiary tests, such as those concerning chemical analysis, weathering qualities, or friction coefficient of a material, are made with reference to their effect on the primary characteristics. Since textile requirements in other fields are somewhat similar, the testing equipment for parachute textiles has been borrowed or adapted from these other fields. Perhaps the principal difference in the parachute field is a shifting of emphasis. Characteristics such as permeability and elongation on the lond are more thoroughly investiaged. The methods described in the following paragraphs are primarily for textile testing. Some testing is done on parachute hardware, but this has followed the same pattern as any metal testing -- that is, bending and hardness test, and spectrographic and chemical analysis. A number of instruments are commercially available for all of these tests.

2.5.2 AIR PERMEABILITY. Through its control of the air mass inside the canopy and the flow over it, the air permeability of the fabric is an important factor affecting parachute performance characteristics such as critical opening velocity, opening shock, and stability. Air permeability is measured by clamping a fabric specimen tightly over an orifice. The air flow is either drawn or blown through the fabric

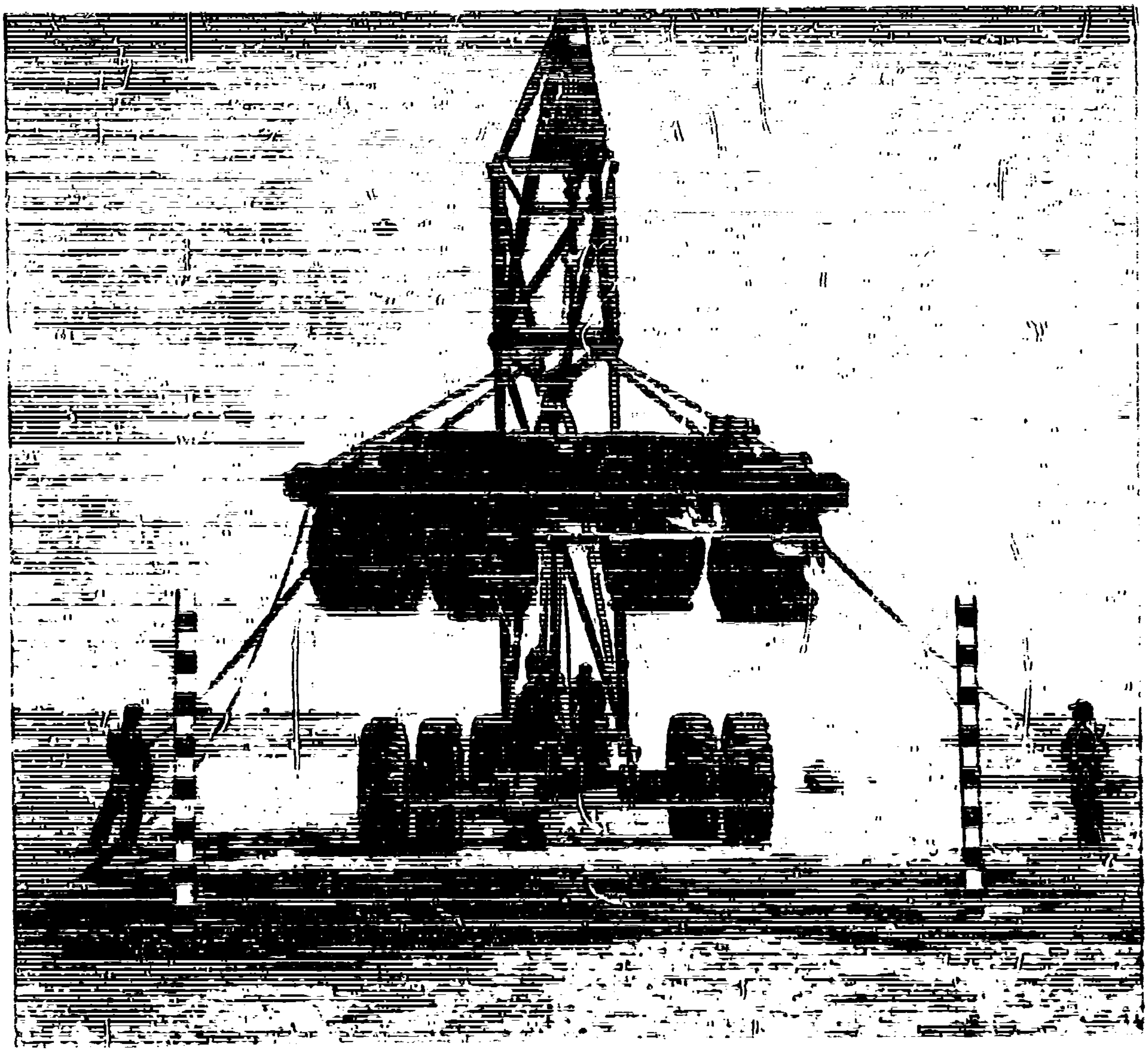


Figure 8-2-4. Platform Drop Test (Static)

specimen. The standard method has been to measure flow in terms of cubic feet per minute per square foot of area with 0.5 inch of water pressure drop across the fabric specimen.

2.5.3 STRENGTH. The strength of a textile material is usually measured by clamping a specimen between a fixed and movable set of grips or jaws and subjecting it to pull or tension. The loading can be imposed to the point of rupture or to any lesser value. The elongation and energy absorption can be determined and, in some instances, pencil-graphed directly from the instrument. Tensile strength is usually expressed in terms of pounds, kilograms, or grams per width of the specimen for webbings, tapes, and ribbons; per specimen shaped area with fibers, yarns, threads, and cords; and per inch width in the case of fabric. Strength factors are measured under many different conditions, depending upon the study being made. But normally, they are expressed in terms of standard dry specimen conditions at 70° F and 65 percent relative humidity. The proper grip or clamp is as important as the tensile testing instrument. If the specimen is not held correctly, errors will result. A specimen undergoing a tensile test must have the load applied uniformly across the specimen, or a tearing action will result. That is true regardless of the type of instrument used.

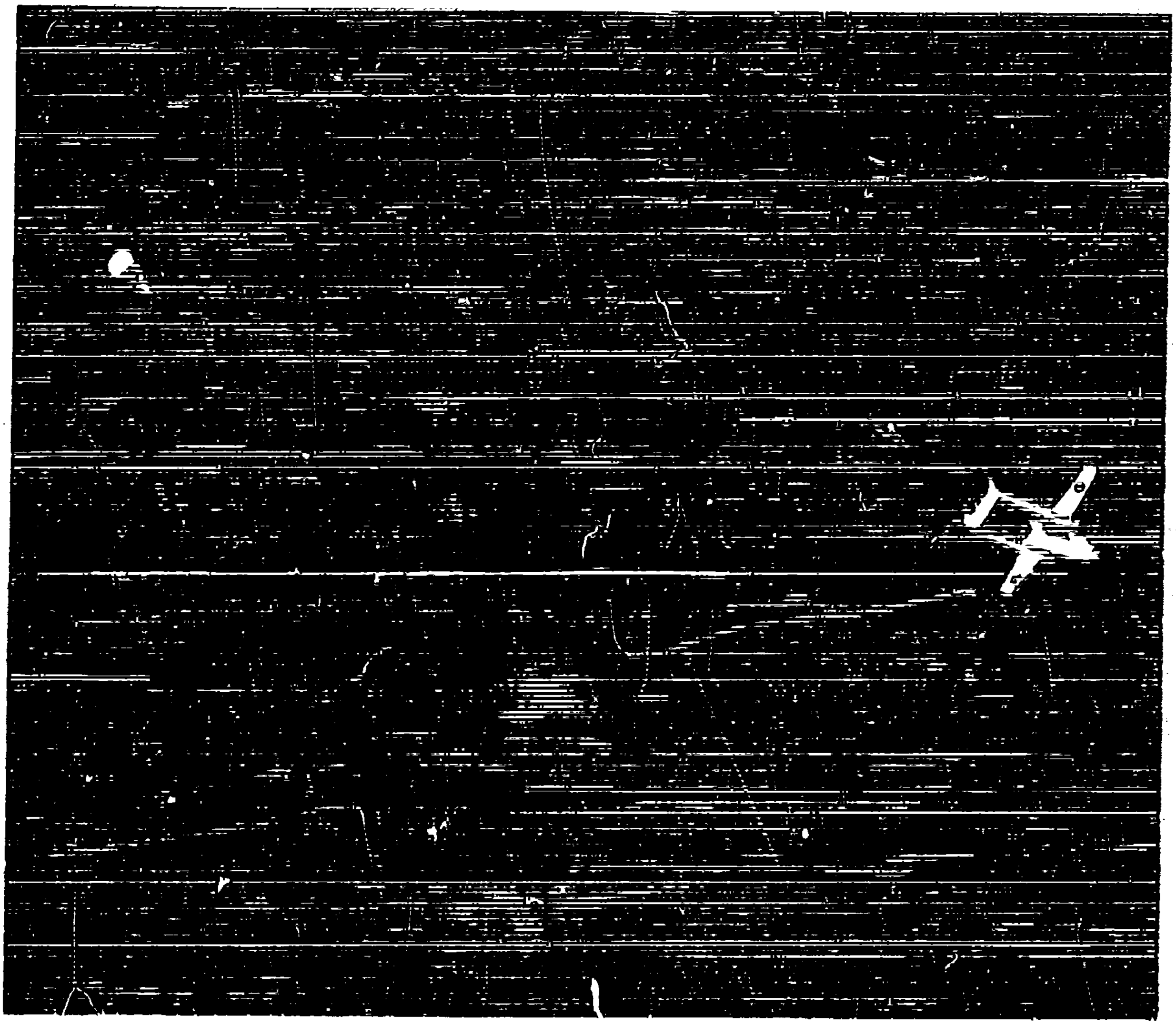


Figure 8-2-5. Aircraft Drop Test

2.5.4 TEAR RESISTANCE. Tear resistance is considered an essential characteristic of parachute textile fabric and is a physical test requirement outlined in parachute fabric specifications. The usual tensile testing instruments are used to pull the specimen on test. Two methods are used for determining tear resistance: the tongue method and the trapezoid method. The tongue method is used to determine the tearing strength of woven fabrics that have approximately the same tearing strengths in both warp and filling directions. The trapezoid method is used for fabrics that have unequal warp or filling strengths.

2.5.5 HEAT AND FRICTION. Because of present high-speed applications, heat resistance has become an important property of parachute textiles. The generation of heat by friction has also made it important to know the coefficient of friction of the fabric. For determining the static coefficient of sliding friction, the inclined plane type of apparatus is the simplest in construction, operation, and calibration. The inclining of a plane to the horizontal is gradually increased and the angle measured at the instant when a block begins to slide down the plane. The tangent of this critical angle is numerically equal to the coefficient of static friction of whatever material is on the block and plane surface. The tangent is measured by means of a vertical scale fixed behind the inclined plane at a known distance from the rotational center of the plane. In addition to the tests described, a variety of

Figure 8-2-6. Wind Tunnel Tests

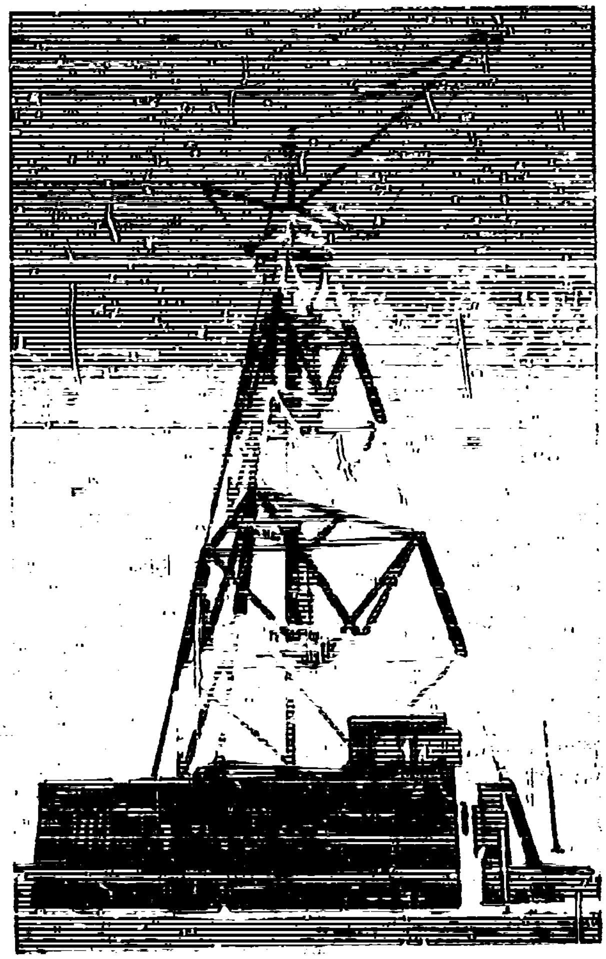


Figure 8-2-7. Parachute Whirl Tower

miscellaneous tests are made on parachute cloth. These material tests are described in Specification CCC-T-191B.

2.6 WHIRL TOWER TESTS.

2.6.1 GENERAL. (See Figure 8-2-7.) Scientific development and rigorous test evaluation of parachutes have been retarded by the difficulty of conducting and observing controlled experiments with large or full-scale models under normal or near normal operating conditions. Consideration of this problem led to the development of the Whirl Tower Test Facility at El Centro, California. In addition to providing precise speed controls and predictable flight path data, the whirl tower provides free fall test data and evaluation of large-scale parachutes by permitting release of the parachute load system from all restraints during the test. This is made possible by mounting the test vehicle with a parachute pack on a release device inside a streamlined missile suspended from the whirling arm of the tower. Parachute deployment is effected immediately after release by means of an electrical squib and a short static line attached to the test vehicle. Since the action of centrifugal force ceases at the instant of release, the free-flying parachute-load system follows a predetermined course similar to the trajectory encountered in normal drops from aircraft. The height of the release point generally is sufficient to enable the canopy to reach the stabilized, fully inflated condition of normal operation for a brief interval prior to touchdown of the test vehicle. Because the flight trajectory is short and its direction reproducible within narrow limits, very complete fixed instrumentation coverage is possible. Structurally, the parachute whirl tower consists of a truncated steel tripod erected to support a vertical central drive shaft. At a point 120 feet above the ground, a counterbalanced boom is

secured to the central drive shaft. From the arm of the boom, 86 feet outboard of the central drive shaft, a 114-foot long flexible steel cable is suspended. The cable supports a streamlined missile which incorporates provisions for carrying and releasing test vehicles and the parachutes to be tested. The whirl tower with a maximum working radius of 172 feet and a 2,800-hp. drive motor was designed to accelerate a 230-pound dummy load to a rotational velocity of 435 knots. At 435 knots the g force is 96.6. The following types of parachute tests conducted on this test facility are defined as:

a. Reliability; the consistency and uniformity of deployment and opening processes over a large number of tests.

b. Functional general behavior of a parachute.

c. Performance evaluation (characteristics data).

d. Strength evaluation (destruction tests).

e. Basic research tests in support of theoretical studies

The whirl tower never can be suitable for a complete study of a parachute's behavior, because the maximum drop altitude is fixed at 120 feet by the tower's height. In its present state, the facility is not suitable for performance of tests that require speeds beyond 435 knots, load weights of more than 300 pounds, or parachutes larger than 32 feet in diameter. It appears to be possible to undertake and accomplish a running average of six drops an hour. Obviously, this number will be reduced by occasional, normal delays, and will be less for more complicated tests employing special instruments and/or unusual procedures. Besides the evaluation of parachutes of various designs and different applications, such parachute accessories as harnesses, fittings, deployment bags, static lines, and pilot and extraction chutes, devices associated with deployment may be thoroughly tested. The behavior of parachutes in the reefed condition may also be observed and measured.

The whirl tower provides these important advantages:

a. Rapid programming (up to six drops per hour).

b. Cheapness.

c. Short static line control keeps speed decay to a minimum.

d. Release position may be controlled or kept constant.

e. Very exact duplication of tests for comparative purposes is possible.

f. Scale-down chutes may be used to determine trends.

Disadvantages are:

a. Relatively short deployment system must be used.

b. Size and weight are limited. Maximum weight of parachute-load combination is 230 pounds. (See Figure 8-2-8 for reduction in speed necessary with increase in weight.)

c. Drop time is very short and rate of descent tests are not possible. (See Figure 8-2-9 for height above ground versus time after release -- the longer time at high-speed release is due to more rapid opening.)

8.2.3 RELIABILITY TESTS. A determination of the consistency and uniformity of parachute opening over a statistically significant number of operations requires very little instrumentation. Accurate data may be obtained through the use of stopwatches and/or photographic equipment. It is also possible through use of the correct

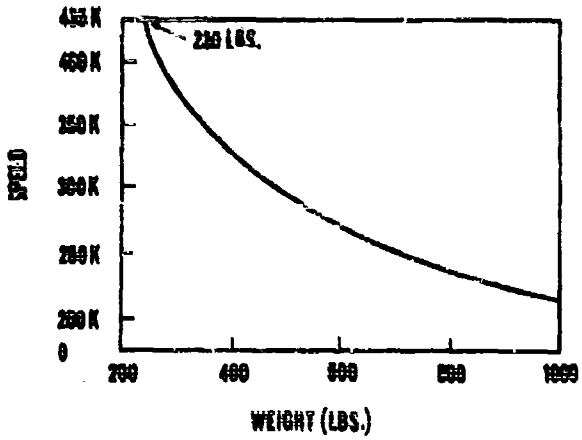


Figure 8-2-8. Design Speed Versus Weight for Whirl Tower Tests

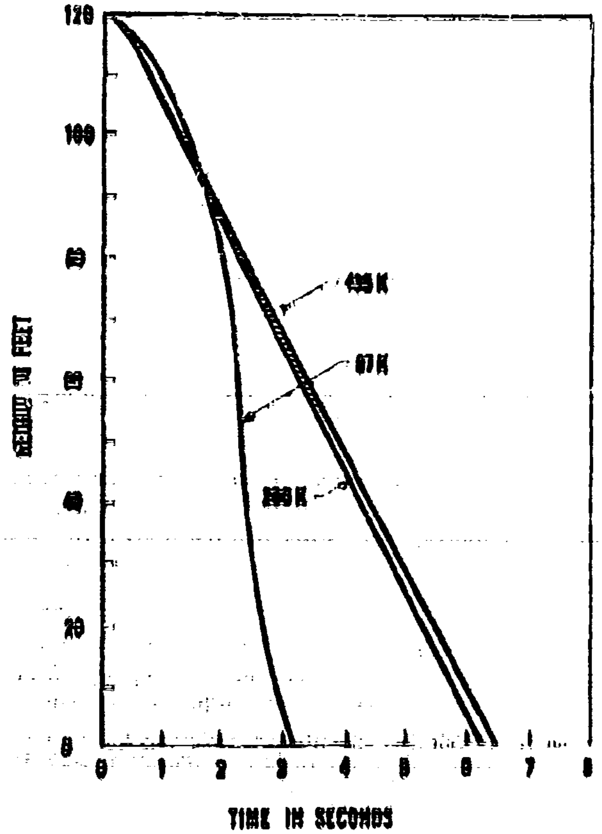


Figure 8-2-9. Height Above Ground Versus Time After Release

lengths of static line to reproduce with sufficient accuracy the conditions of test drops from aircraft. Although the height of the tower is less than the drop height specified for opening reliability and tests of personnel parachutes with twisted lines, a preliminary indication of the ability of the parachute to pass such tests may be obtained. The height of the tower is also less than that specified for minimum altitude opening reliability tests, and thus provides a severe minimum altitude test for parachutes of all types.

2.6.3 FUNCTIONAL TESTS. A general determination of the characteristic behavior of a new or modified parachute can be accomplished with very little instrumentation. With the exception of stability and rate of descent, the significant information needed may be obtained with stopwatches and minimum photographic equipment, such as a 16-mm. motion picture camera and a 4 x 5 sequence still camera.

2.6.4 PERFORMANCE EVALUATION TESTS. A complete evaluation of the performance characteristics of parachutes cannot be made with the Whirl Tower Test Facility. However, with the exception of oscillation, gliding, and similar characteristics associated with steady descent, all of the basic data required can be obtained. Suitable instrumentation may be employed and all data recorded versus a common time base. Either telemetering or magnetic tape recording systems may be used in connection with suitable sensing elements.

2.6.5 STRENGTH EVALUATION TESTS. Strength evaluation tests of parachutes, commonly referred to as destruction tests, entail making a series of successively higher velocity tests until extensive damage or destruction of the parachute results. The opening shock force may be measured and recorded very satisfactorily by means of Exline-type self-recording tensiometers.

2.6.6 BASIC RESEARCH. A variety of parachute tests in support of general theoretical and empirical studies may be performed effectively with the whirl tower. Fabric workers can make alterations while tests are still in progress. Various methods of packing may be tried and compared. Instrumented tests could yield valuable data on all aspects of parachute deployment and opening processes, both for further study of the physical laws governing parachute behavior and for substantiating theories and methods developed on such subjects as stresses in parachute canopies and the effect of varying design parameters on parachute performance. (See Figure 8-2-10.)

2.7 AIRCRAFT TOW TESTS.

2.7.1 GENERAL. The towing of parachutes behind aircraft has proven to be a satisfactory method of testing parachutes, particularly for applications in which the parachute is used in conjunction with aircraft in-flight or landing deceleration. Since it is becoming standard practice to equip jet fighter and bomber type aircraft with deceleration parachutes, the parachute system for a particular installation should be tested behind the designated aircraft. In this manner only, the performance characteristics of the parachute system can be accurately determined under actual conditions. This is essentially true where wake effects are encountered.

2.7.2 B-26 "WINGLESS WONDER" TEST VEHICLE. (See Figure 8-2-11.) The B-26 "Wingless Wonder" has been, and is being, used

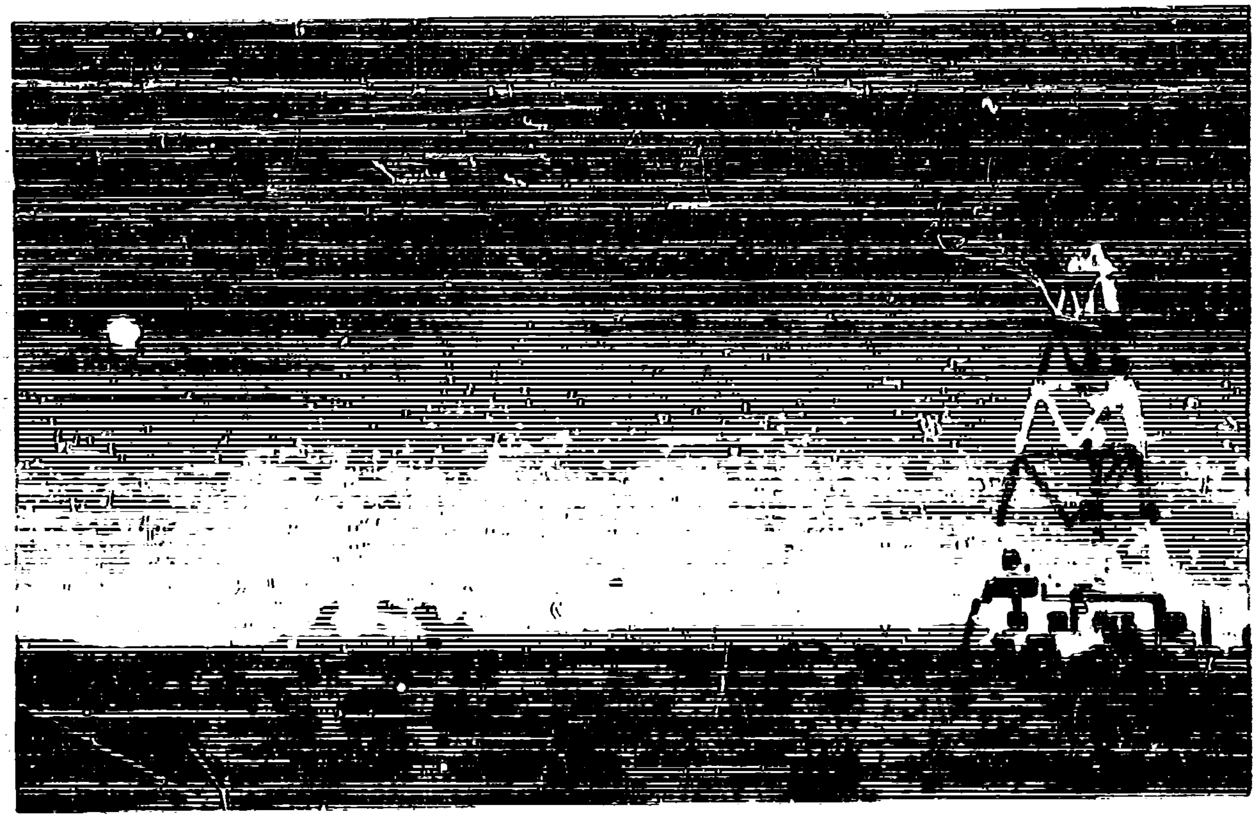


Figure 8-2-10. Parachute Whirl Tower in Operation

extensively to obtain performance data on various parachute designs and to evaluate the performance of parachute systems for aircraft landing deceleration applications. Parachute deployment characteristics can be obtained at speeds up to 130 knots on a 10,000-foot-long runway. Parachutes of diameters up to 32 feet have been tested. Instrumentation to measure and record parachute force, ground speed, and various other phenomena versus a common time base is installed in the test vehicle. The weight of the aircraft is approximately 30,000 pounds.

8.7.3 B-47 IN-FLIGHT TESTS. (See Figure 8-2-12.) To measure specific parachute performance characteristics at higher deployment

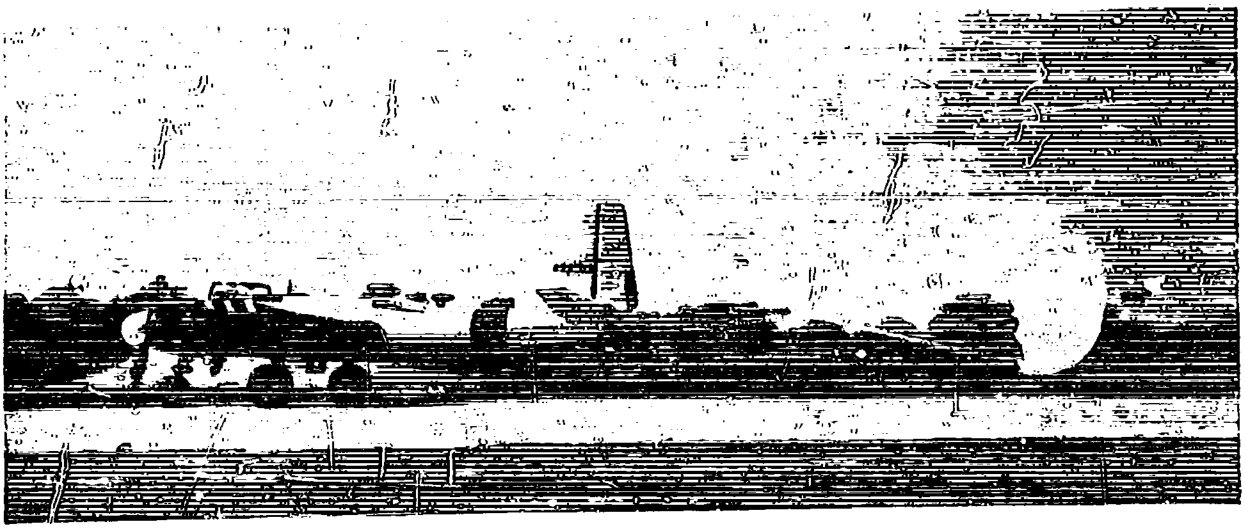


Figure 8-2-11. B-26 "Wingless Wonder" Test Vehicle

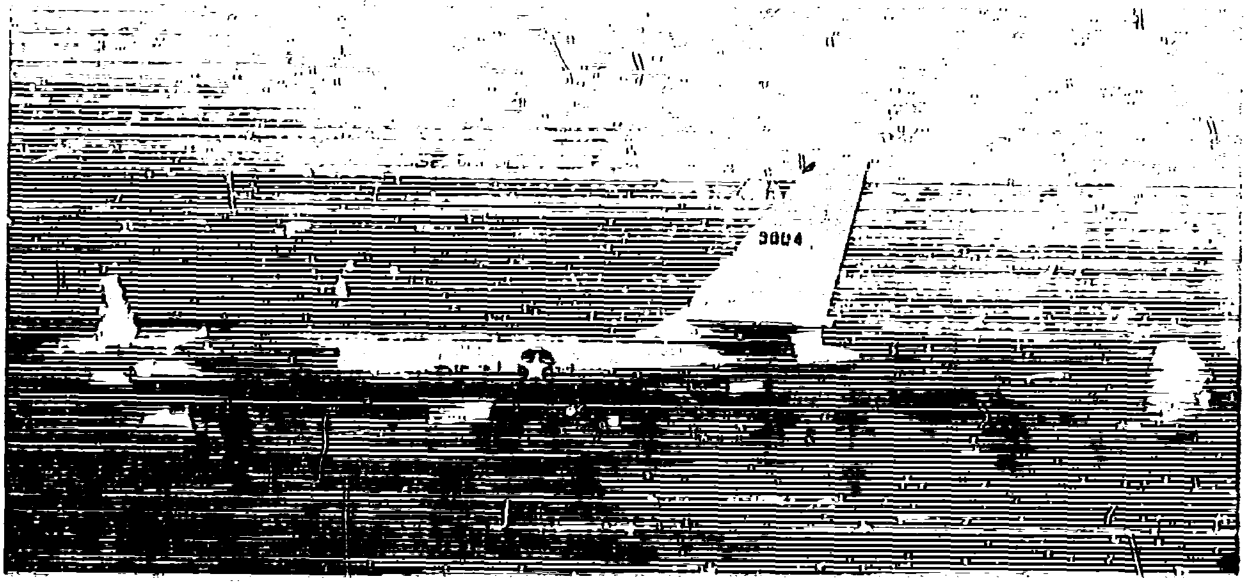


Figure 8-2-12. B-47 Aircraft Used for Parachute Test

speeds and to evaluate the performance of parachute systems for aircraft in-flight applications, a B-47 type aircraft has been used successfully as a test vehicle. Parachutes in sizes of up to 16 feet in diameter may be deployed at speeds of up to 195 knots without impairing the safety of flight. The B-47 aircraft is equipped with instrumentation to measure and record parachute forces, aircraft speed, and other parachute phenomena versus time. The weight of the aircraft during test is approximately 120,000 pounds.

2.8 PROJECTILE GUN TESTS.

2.8.1 PARAGUN. (See Figure 8-2-13.) The projectile gun (Paragun) for the testing of model parachutes provides an economical method of obtaining both qualitative and quantitative performance data over a wide range of dynamic conditions. The Paragun is essentially a smoothbore cannon having a 20-foot barrel and a 10-inch bore. The propulsion pressure is achieved by an air pump pressure built up to 1,400 psi in a closed pressure chamber behind the projectile. This 1,400 psi is then increased to 2,800 psi by calrod heating units. Discharge is achieved by a hydraulic pressure release system. This device is well adapted for the execution of a series of test shots with great rapidity. The type of trajectory desired can be obtained by varying the elevation of the gun, and this in turn determines the location of some of the range instrumentation. Low elevations are best for close observation of high-velocity deployment, while high elevations permit the close observation of the parachute during the descent phase. One of the major disadvantages of this test method is that in the event high subsonic or low supersonic parachute deployment is desired, the weight of the test vehicle has to be relatively light, thus reducing the test parachute to moderate size. (See Figure 8-2-14.) One of the problems encountered in the development of the parachute gun system is that of assuring rapid and reliable deployment of the parachute after the projectile is clear of the barrel. This is complicated by the presence of the driving plate, which must separate from the base of the projectile first, when deployment from the side of the projectile is not feasible. Another major problem is seen in the development of an instru-

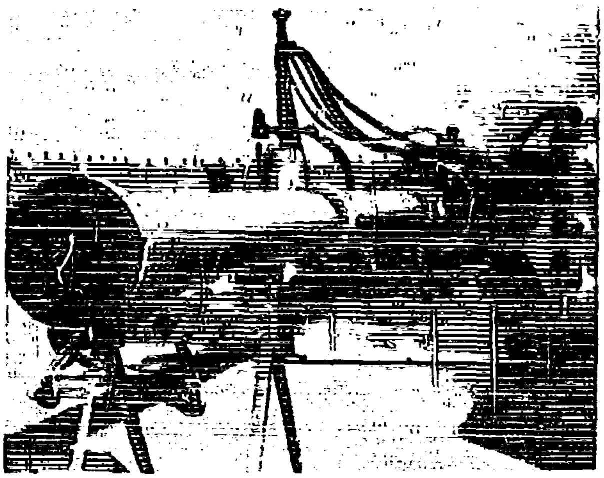


Figure 8-2-13. Paragun

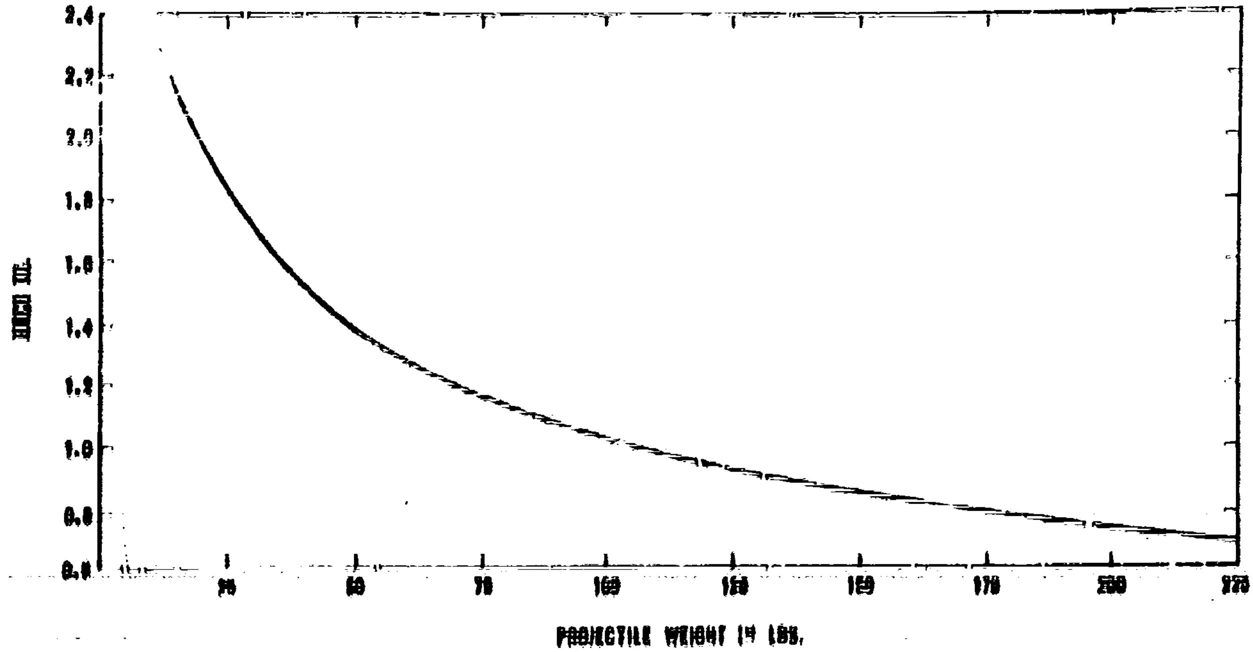


Figure 8-2-14. Paragun -- Design Velocity Versus Projectile Weight

ment system that will be able to sense and record desired parachute phenomena under sustained gravitational forces encountered during all phases of the test. A number of projectile gun designs have been tested in the past.

2.9 ROCKET SLED TEST.

2.9.1 GENERAL. Free air test facilities are being used sucessfully for determining the aerodynamic characteristics and performance of parachutes and parachute systems at subsonic, transonic, and supersonic speeds. Basically, a free air test facility consists of a straight, precision-aligned track along which powered test sleds are moving. The parachute or system to be tested is mounted to the test vehicle. The free air test facilities have a number of advantages over other test methods among which are most important:

a. Large size or even full scale parachutes or systems may be tested; thus, dimensional scale factors need not be considered.

b. There are no tunnel blockage problems.

c. Conductance of tests is relatively inexpensive.

There are, however, several disadvantages to this test method, such as: the actual usable test period is of short duration, since it is limited by the track length and by the time during which the sled can be maintained at required test velocities; also, consideration must be given to the effects of lateral and vertical vibrations, acceleration, and cross winds. Two different types of rocket powered sled test vehicles are presently being used for the testing of parachutes and parachute systems. (See Figures 8-2-15 and 8-2-16.)

2.9.2 SOLID-FUEL PROPELLED ROCKET SLED. The overall configuration and dimensions of the vehicles are shown in Figure 8-2-17. The test vehicle is a greatly modified JB-2 launching car assembly designed to operate on the 10,000-foot track of the Edwards Air Force Base Free Air Test Facility. Two to five T10-E-3 or X102C1 JATO units are used to power the vehicle. The maximum speed of the test vehicle with five JATO units is about 480 knots; with fewer JATO units the maximum speeds are correspondingly less. Intermediate velocities for parachute deployment are obtained by allowing the sled to coast for a predetermined interval between JATO burnout and parachute deployment. The basic weight of the test vehicle or sled is approximately

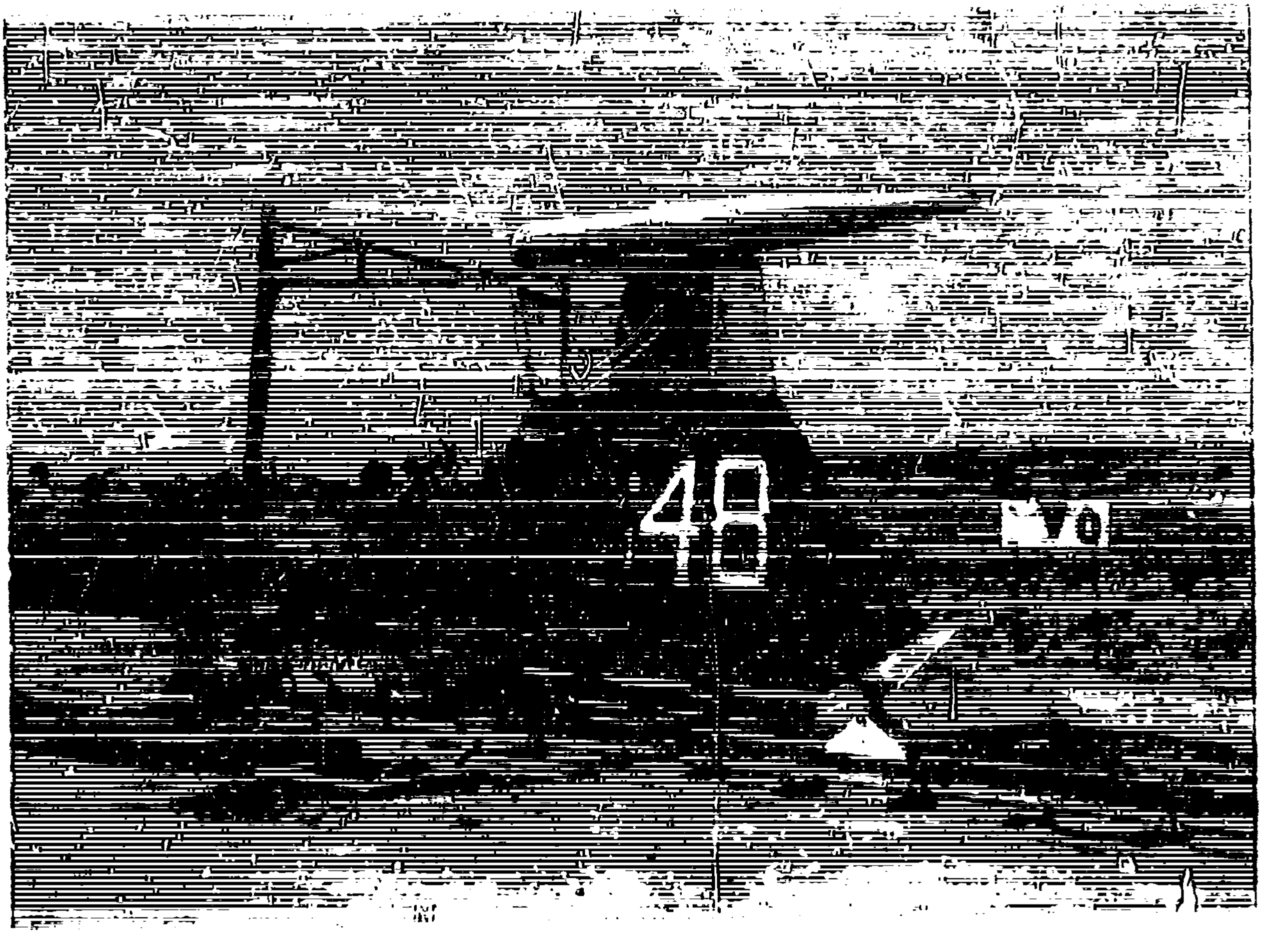


Figure 8-2-15. Subsonic Test Sled

2,400 pounds. The basic JB-2 sled consists of a large aluminum tube as a main structural member, with cast magnesium cross-members supporting it at each end. The rear cross-member is made in two sections, so that it can serve as a clamp or mount for the JATO propulsion units. On the ends of the cross-members are mounted separate slippers, which ride on the rails. An aluminum structure is built on the JB-2 sled to provide a parachute attachment point 108 inches above the rails. The capsule at the top of the structure contains a magnetic tape recording system and the parachute compartment. The test vehicle is shown in action in Figure 8-2-18.

2.9.3 LIQUID-FUEL PROPELLED ROCKET SLED. Figure 8-2-19 shows the overall dimensions and configuration of this sled test vehicle. The main structural member of the sled is the high-pressure nitrogen tank, which is 10 inches in diameter. Box frame cross-members are welded to each end of the nitrogen tank. The alcohol and liquid oxygen propellant tanks are 12 inches in diameter and are attached to either side of the nitrogen tank with fixed supports at the rear. The front supports permit longitudinal movement to accommodate growth or shrinkage of the tanks. The tubular diagonal support between the front of the sled and the parachute attachment point also acts as an auxiliary source of high-pressure nitrogen for the engine control system. The sled is powered by a gas-pressurized, liquid propellant rocket motor. The fuel for this motor is a mixture of 75 percent ethyl alcohol and 25 percent water. The oxidizer is liquid oxygen. A gaseous mixture of nitrogen and helium is used for pressurizing the fuel system. The thrust is adjustable from 30,000 to 50,000 pounds. The maximum duration at 50,000-lb. thrust is approximately 4.8 seconds. The weight of this sled test vehicle is approximately 4,000 lb. and the maximum speed attainable approximately 750 knots. The thrust chamber body of the engine is of conventional design, with a chamber to throat area of 2 to 1 and an expansion ratio of 3.65 to 1. The injector is of the triplet impinging type. Ignition is obtained with two integral alcohol-oxygen igniters which are fired by

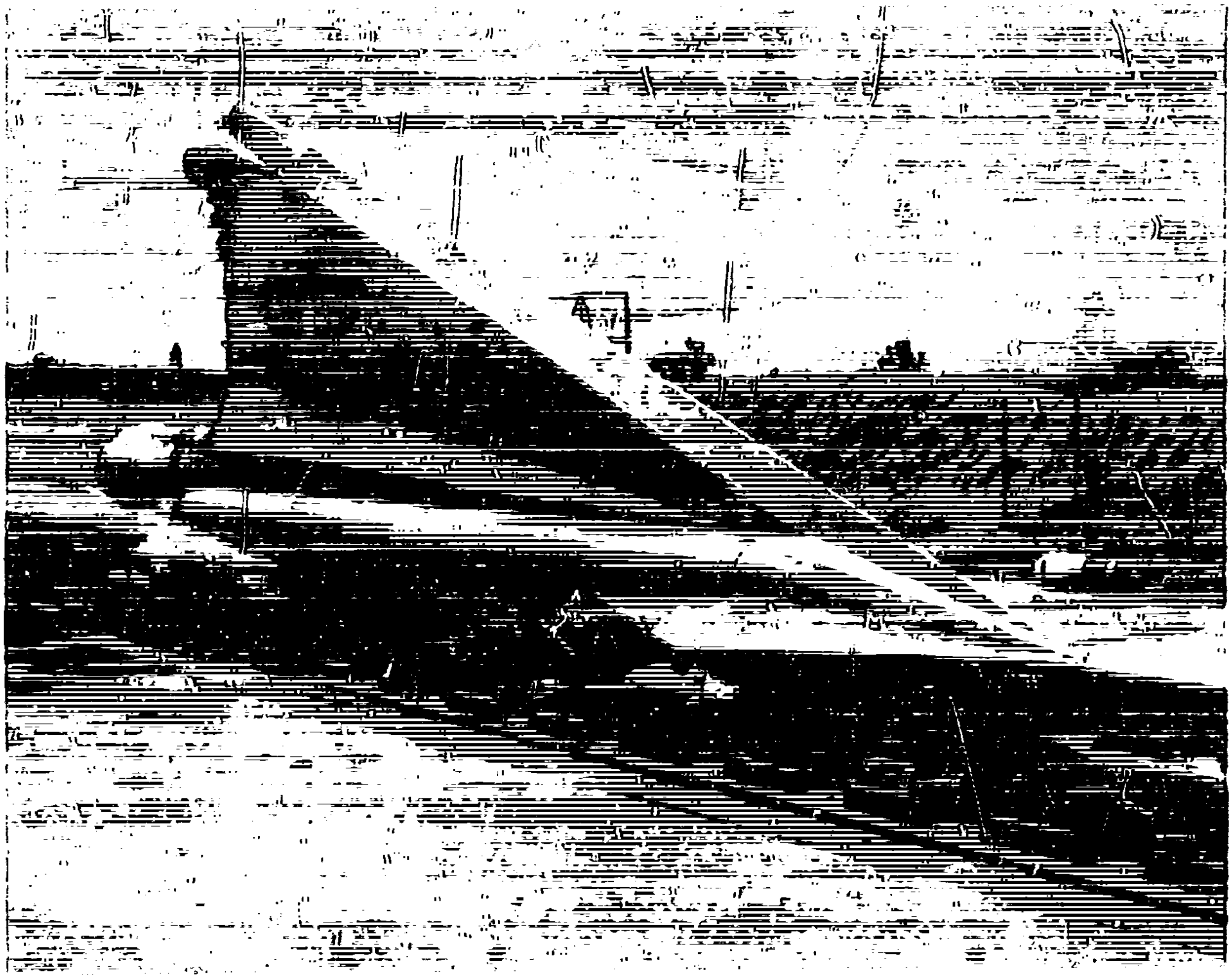


Figure 8-2-16. Supersonic Test Sled

aircraft type spark plugs. All valves are pneumatically controlled by 750-psi nitrogen supplied through solenoid-actuated valves. Here again, as in the case of the solid-fuel propelled rocket sled, separate slippers, which ride on the rails, are mounted on the ends of the front and rear cross-members. A compartment containing the parachute is mounted to the top of the sled structure providing a parachute attachment point 108 inches above the rails. Instrumentation, consisting of a multichannel data tape recording system, is contained in a separate compartment located on the side of the sled.

2.3.4 TEST SLED OPERATION. (See Figure 8-2-20.) The parachute to be tested is packed in a suitable container on the sled. Rocket motors are ignited from a blockhouse near station zero, and the sled accelerates to the required test speed. A knife blade is mounted on the track at the station where it has been predicted that this test speed will occur. This knife cuts a wire on the sled, which in turn actuates a powder charge in a blast bag that ejects the parachute to be tested. The parachute suspension lines, risers, are contained in a canvas bag during ejection. As the pack travels to the rear, the riser is deployed from the bag first, suspension lines second, and finally the canopy. With this typical deployment method, the peaks of snatch force and opening shock are separated and the overall maximum load is reduced. The riser is connected to a tensiometer at the front of the parachute compartment. Tensiometers with full-scale loads of up to 100,000 pounds may be used. As the sled decelerates to approximately 85 knots the riser is disconnected to allow the parachute to drop to the track. The duration of parachute operation during which data may be obtained is usually between 5 and 10 seconds. A water trough between the rails of the last 2,000 feet of

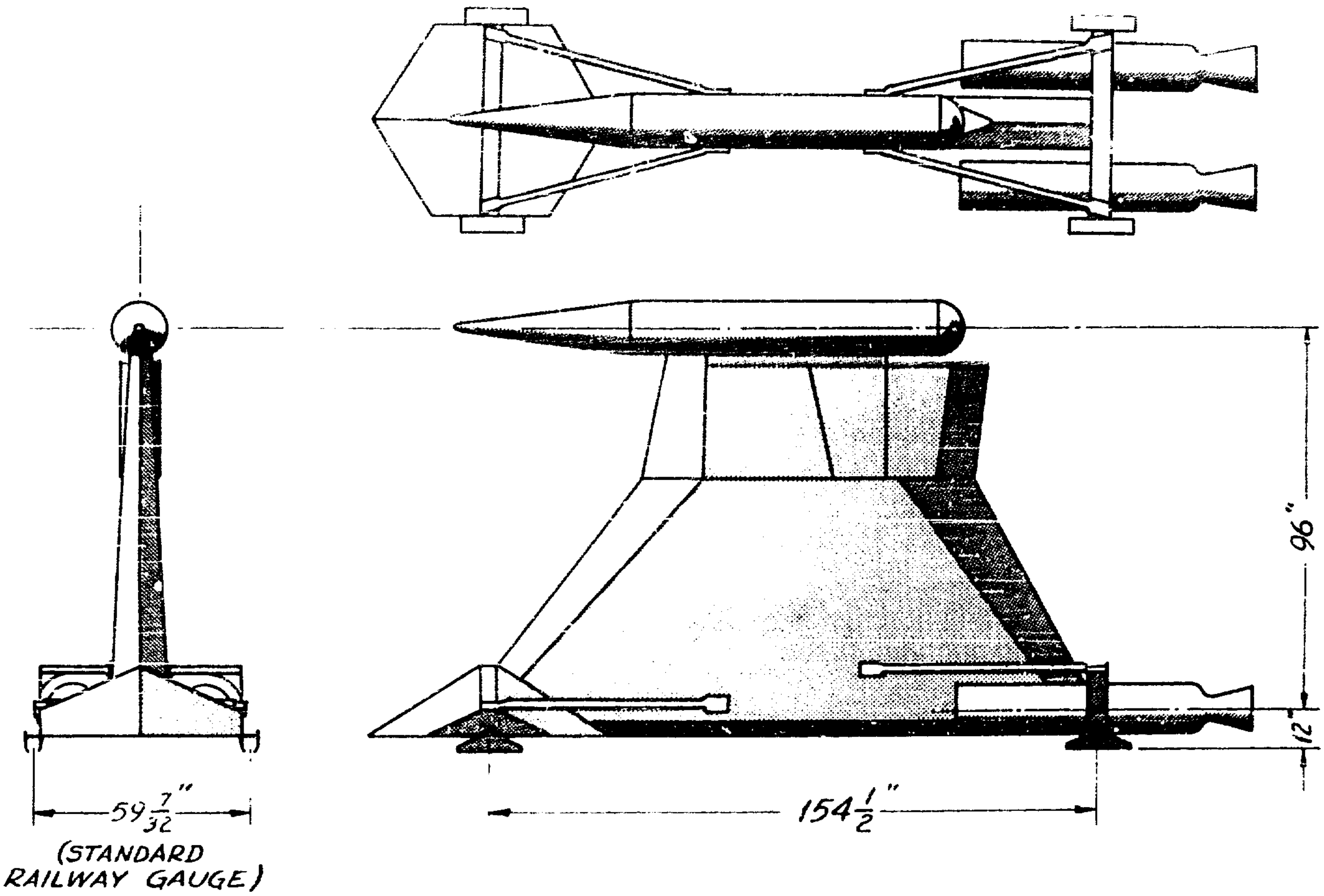


Figure 8-2-17. Subsonic Test Sled -- Dimensions

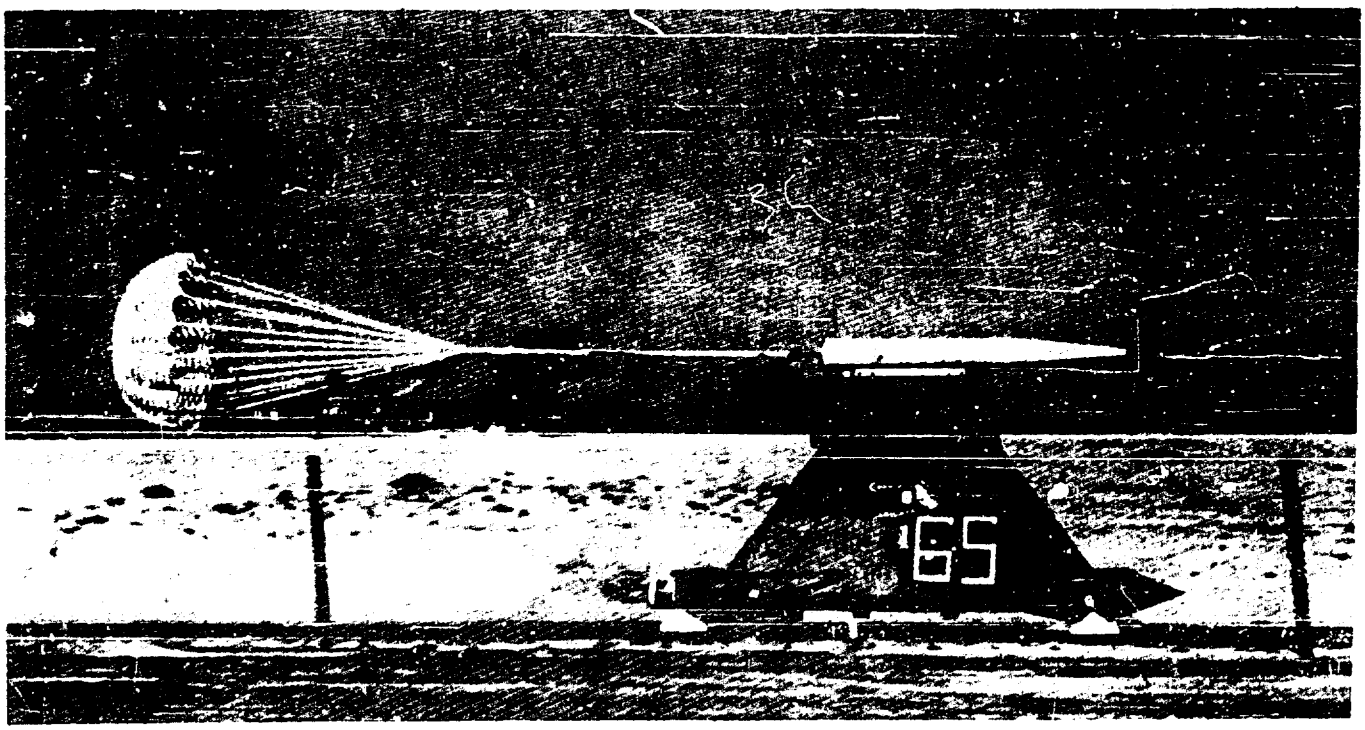


Figure 8-2-18. Subsonic Test Sled in Operation

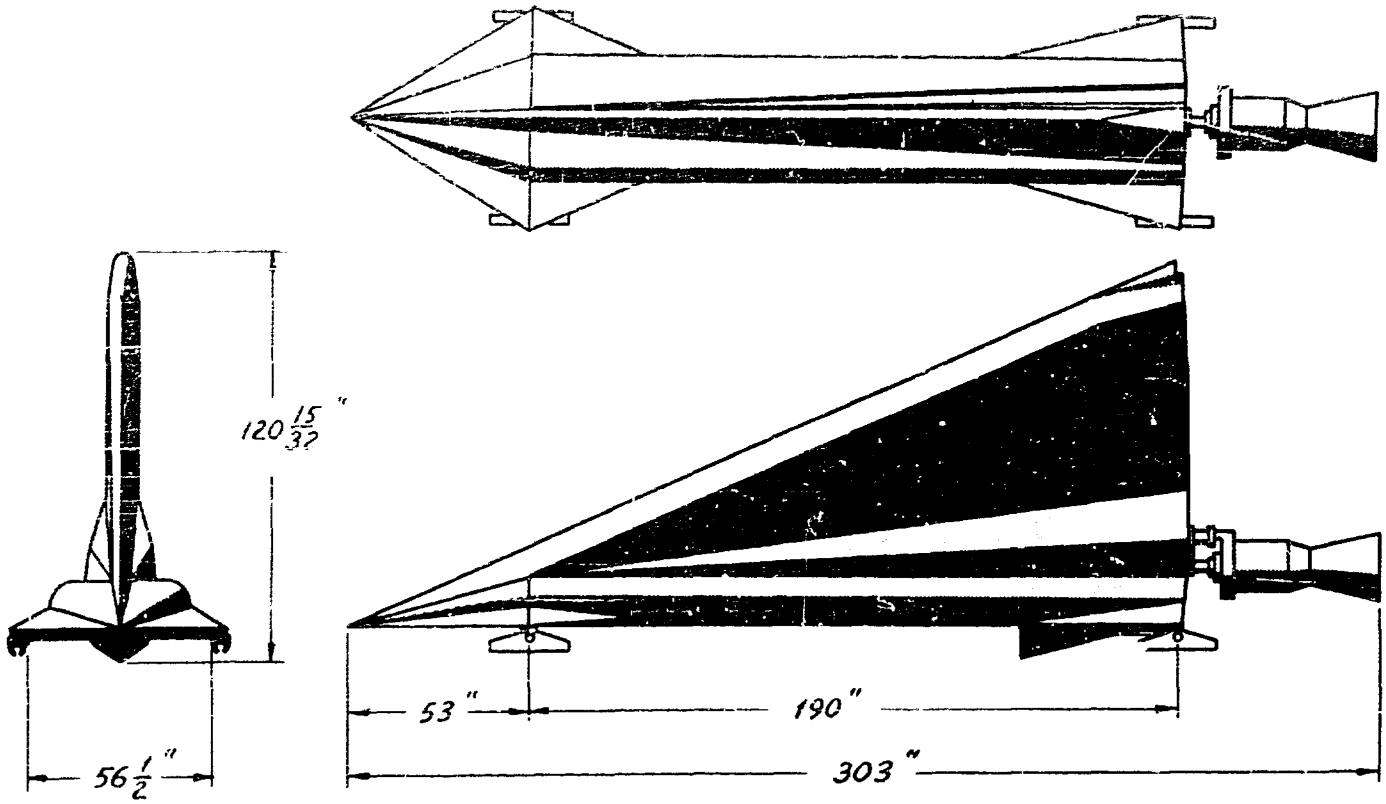


Figure 8-2-19. Supersonic Test Sled - Dimensions

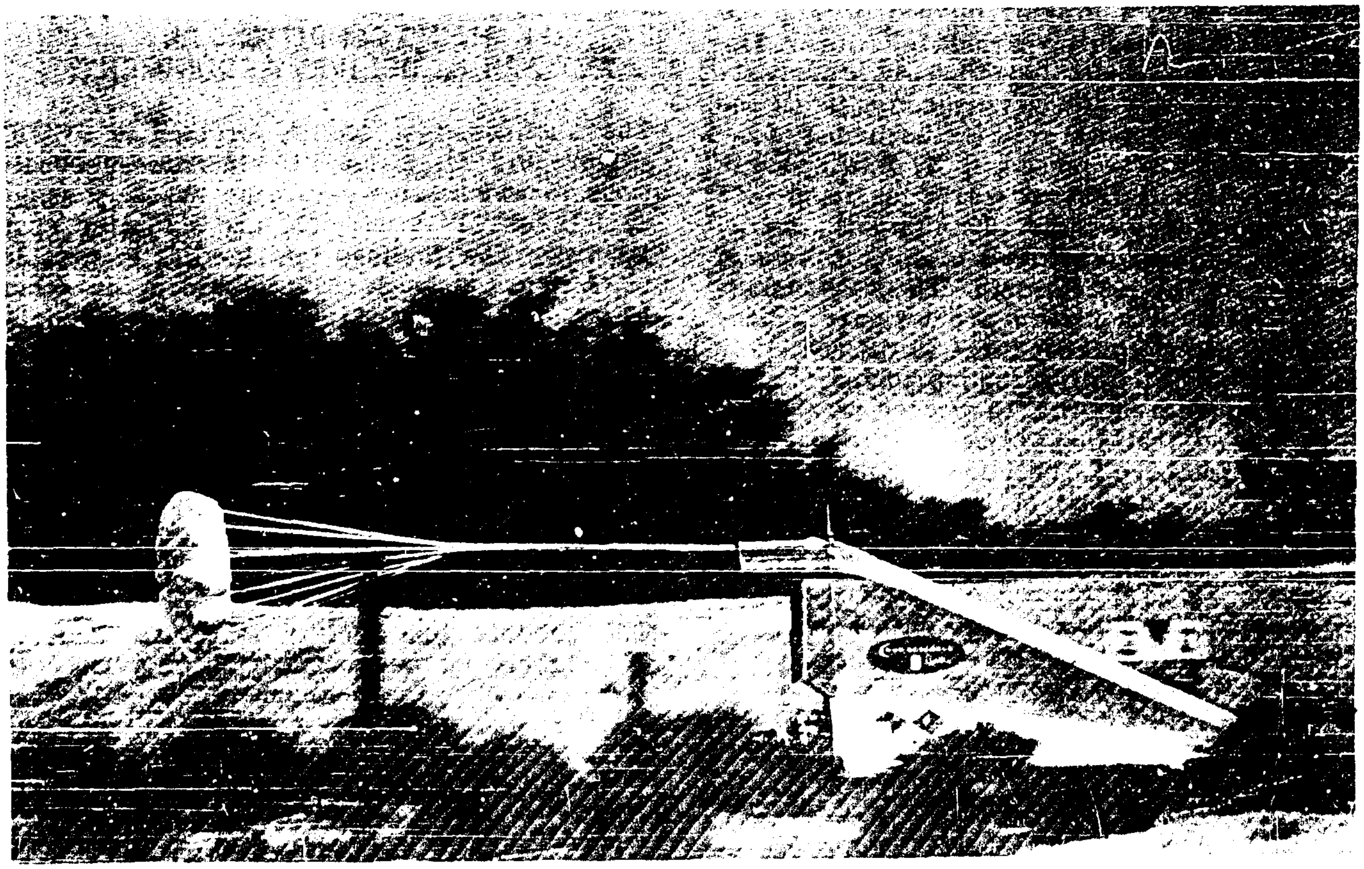


Figure 8-2-20. Supersonic Test Sled in Operation

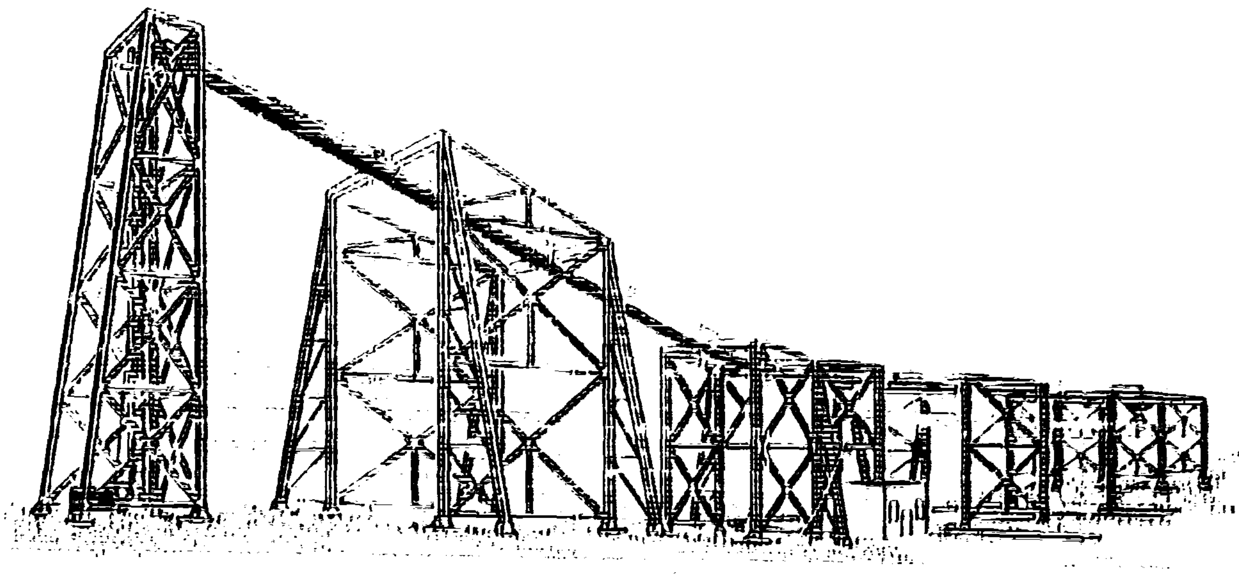


Figure 8-2-21. Inclined Test Facility

track serves as a braking method to stop the test vehicle in case of parachute failure. The track over this length slopes downward approximately 6 inches. A scoop projecting below the vehicle enters the water at the beginning of the trough. The water picked up by this scoop is discharged in a forward direction from both sides of the test vehicle. This imparts energy to the water and provides a braking force as a reaction on the test vehicle. The water intake shape and the track slope are designed to provide a constant braking force as the vehicle is decelerated. The slippers, fabricated of steel and lined with stellite to reduce wear, are designed so that they cannot be lifted from the rail but have to be taken off or put on by sliding from the end of the rail. Thus, the vehicle is held captive to the track regardless of the direction of the forces exerted on the slippers. Small permanent magnets are mounted at 50-foot intervals along one side of the track and a coil is mounted on one of the slippers in such a manner that it passes close to the magnets as the sled moves along the track. The resulting pulses are recorded on the magnetic tape, and, when compared to the time base, give a measure of sled velocity.

8.10 INCLINED TEST FACILITY FOR SIMULATING LANDING CONDITIONS ON HEAVY AERIAL DELIVERY EQUIPMENT.

The inclined test facility erected at WADC (Figure 8-2-21) is used to simulate the conditions to which cargo platforms and other heavy aerial delivery equipment are subjected upon landing. The inclined test facility is capable of lifting a loaded cargo platform or other heavy aerial delivery container weighing up to 25,000 pounds from a vehicle or the ground and accelerating these to provide, upon ground impact, any desired combination of horizontal velocity up to 50 ft. per sec and any vertical velocity desired between 20 and 35 ft. per sec. The facility is capable of retrieving a load that has been dropped and repeating the cycle without such additional equipment as trucks or cranes.

The inclined test facility structure consists of columns and beams mounted on reinforced concrete footings, which support a central monorail for a cargo and control trolley. The control trolley has the purpose of pulling the cargo trolley up the incline to a predetermined point from which the cargo trolley

is released to accelerate down the incline. The control trolley therefore is equipped with an automatic coupler that can be actuated by an electrical solenoid. The cargo trolley carries the platform or container to be tested and is equipped with a mechanical load release actuated by cams on the monorail in the drop test area. An adjustable spring-loaded brakeshoe works in conjunction with the release so that upon release of the load, the trolley brakes against the monorail and comes to a stop on the remaining portion of level rail.

The test facility is completely instrumented so that such phenomena as impact velocity, gravitational forces, pressures in air bags, stresses in load arresters and antitoppling devices, as well as general performance of the equipment upon ground impact may be accurately measured and recorded.

Advantages of this test method:

a. Accelerated testing of heavy aerial delivery equipment and components can be conducted.

b. The effect of various soil compositions in the impact area upon equipment landing performance may be studied.

c. Performance characteristics can be measured and recorded with substantially higher accuracy than is possible during aircraft drop test, and superior photographic coverage is available.

CHAPTER IX

SECTION 1

REPORTS

WADC TR 53-79, Volume I - Bibliography and Summary of Extracts (Confidential)
(All publications related to Parachutes and Accessories up to 1953)

1.1 TECHNICAL MEMORANDUM REPORTS (WADC).

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WCLE-52-35	Qualification Tests of Quick Release Boxes, Type B3-A
WCLE-52-36	Ring-Parachute Harness "V", P/N AN6583-1
WCLE-52-37	Qualification; Canopy Assembly, Personnel Parachute, Security Parachute Company
WCLE-52-38	Qualification; Parachute Assembly Personnel, Miller and Sons, Inc.
WCLE-52-39	Qualification of Personnel Parachute Canopy
WCLE-52-60	Qualification Tests of Quick Release Boxes, Type B3-A
WCLE-52-95	Standard Parachute Harness
WCLE-52-97	Qualification; Pack Assembly, Chest Parachute, Rainier Company, Inc.
WCLE-52-103	Qualification; Pack Assembly Personnel Parachute, Guild Products, Inc.
WCLE-52-112	Type G-12 Parachute, Deployment Systems Tests of
WCLE-53-127	Comparative Strengths of Tape Joints Stitched with Nylon and with Cotton Threads
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WCLE-53-147	Heavy Drops from C-119 Aircraft
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WCLE-54-16	Study of High Speed, Low Altitude Drop of 1200 Pound and 1600 Pound Weights by Parachute
WCLE-54-34	Aerial Delivery of 750 Gallon Fuel Tank and Its Associated Pumps
WCLE-54-50	Qualification of Personnel Parachute Canopy
WCLE-54-76	Forces in Static Lines During the Deployment Phase of Type T-10 Parachutes (Live Jump Phase)
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WCLE-52-22	Oakley, R. L.	Troop Parachute - General Textile Mills
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WCLE-52-26	Oakley, R. L.	High Speed Personnel Canopy
WCLE-52-28	Oakley, R. L.	Canopy, Pseudo-Ribbon, Test of

Number	Title	Title
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WCT-52-61	King, T. H. McGill, A. K. Campbell, W. T.	B-47 Drag Device Investigation
WCLE-52-69	Kiker, J. W.	Evaluation of French Deceleration Parachute
WCRT-52-102	Ross, J. H.	Conference Report on Parachutes to be Operated and Stored at High Temperature
WCRT-52-105	Ross, J. H.	The Use of Sillicone Oil in USAF Parachute Cloth
WCRT-52-165	Muse, J. W.	Study of Dacron Yarns in parachute Materials
WCRT-52-182	McLeod, E. L.	The Effect of Yarn Twist on Standard Parachute Fabrics and Experimental Fabrics
WCRT-52-189	Ross, J. H.	Semi-Annual Report, Evaluation of Shock Absorbing Textiles
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WCRT-53-11	McLeod, E. L.	Static Elasticity in Parachute Materials
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WCRT-53-48	Muse, J. W.	Investigation of Mylar-Type Polyester Films for Use in Parachute Canopies
WCRT-53-58	McLeod, E. L.	New Nylon Webbings
WCRT-53-59	Muse, J. W.	Experimental Dacron for Parachute Fabrics
WCLE-53-141	Kiker, J. W.	Strength Test of Type D-1 Deceleration Parachute Riser used on B-47 Aircraft
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WCLE-54-53	Hegele, A. M.	Evaluation of Fehlman Parachute
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WCRT-54-187	Ross, J. H.	Study of Temperature Affecting the Strength of F-100 Drag Parachute Materials
WCRT-54-188	Stanton, P. Y.	Evaluation of Nylon Webbing and Ribbon
WCRT-54-206	Stanton, P. Y.	Improved Nylon Webbings for Parachute Textiles
WCLE-55-6	Engel, H. Jr.	Bridle Line - Pilot Chute, Personnel
WCLE-55-7	Engel, H. Jr.	Loop Attachment, T-10 Deployment Bag, Tests of

1.3 TECHNICAL REPORTS.

AFTR 6053 VOL I	Cook Research Lab Skokie, Ill	Recovery Systems for Missiles and Target Aircraft, Phase 1A (Subsonic)
AFTR 6053 VOL II	Cook Research Lab Skokie, Ill.	Recovery Systems for Missiles and Target Aircraft, Phase 1B (Free-Flight)
AFTR 6053 VOL III	Cook Research Lab Skokie, Ill.	Recovery Systems for Missiles and Target Aircraft, Phase 2 (Transonic)
AFTR 6289	Hoerner, S. F.	Pressure Losses Across Screws and Grids
WADC 52-57	Gimalouski, E. A.	Investigation of Impact Load Absorption Through Suspension Line Elongation
WADC 52-76	Braun, G. W.	Stability of a Whirling Gondola Suspended from a Parachute Testing Tower
WADC 52-135	Huber, F. J. A.	Tests of Rotorchutes
WADC 52-283 Vol I	Goglia, M. J.	Air Permeability of Parachute Cloths
WADC 52-283 Vol II	LaVier, H. W. S.	Air Permeability of Parachute Cloths
WADC 52-283 Vol III	LaVier, H. W. S.	Air Permeability of Parachute Cloths - Effect of Loading on Elastic Properties of Parachute Cloths without Air Flow
WADC 52-283 Vol IV	LaVier, H. W. S.	Air Permeability of Parachute Cloths
WADC 52-283 Vol V	LaVier, H. W. S. Boteler, W. C.	Air Permeability of Parachute Cloths
WADC 53-21	Coplan, M. J.	A Study of the Effect of Temperature on Textile Materials
WADC 53-78 VOL I	Singer, E. Radioplane Co. Van Nuys, Calif	A Study to Establish a Parachute Research and Development Program (Confidential)
WADC 53-78 Vol II	Singer, E. Radioplane Co. Van Nuys, Calif	Summary and Analysis of Existing Parachute Knowledge
WADC 53-298	Bjorksten, J. Lappala, R. P. Roth, R. J.	Investigation of Nylar-Type Polyester Films for Parachute Canopies
WADC 53-361	Bickford, H. J.	Development of 0.9 oz. Nylon Parachute Cloth
WADC 54-4 Vol. I	Cook Research Lab Skokie, Ill.	Bomb Stabilization by Parachute (Wind-tunnel Study) (Confidential)
WADC 54-39	Phipps, R. L.	An Empirical Report on the Effects of Polyvinyl Butyral on Cargo Parachute Shroud Lines
WADC 54-49	McGrath, J. C.	Symposium on Parachute Textiles
WADC 54-117	Muse, J. W.	A Study of the Effect of Temperature on Parachute Textile Materials
WADC 54-468	Bickford, H. J. Kuehl, D. K. Rusk, T. L.	Study of the Control of Permeability of Nylon Parachute Cloth at High and Low Differential Pressures
WADC 54-536	Cloufelter, W. P. Foelsch, Kuno MacLean, R. F.	Study of the Operation and Test Procedures for the Parachute Whirl Tower
WADC 55-48	McGrath, J. C.	Evaluation of Nylon Fabric Finished with XE-112A Silicone Oil (For Use in Cargo G-11A Parachutes)
WADC 55-156	Sobletto, R. A.	Investigation of T-10 Parachute Canopies
WADC 55-162	Lockheed Aircraft Corp., Missiles Systems Division	X-7A Supersonic Ramjet Test Vehicle Parachute Recovery System (Confidential)
WADC 55-264	McCarry, J. W.	Handbook of Parachute Textile Materials and Properties
WADC 55-364	Berndt, R. J. Engel, H. Jr.	Static Line, Type T-10 Troop Personnel Parachute, Aerial, Dynamic and Static Tests
WADC 55-460	Coy, R. G.	Mechanics of a Parachute Static Line System

WADC 55-464	Markham, R.W.	Flight Test Results of the F-101A Jettisonable Wheels Test on an F-84G Aircraft
WADC 55-665	Kentucky Research Foundation, Lexington, Ky.	Parachute Disreefing Program, Design Study
WADC 55-703	Stanton, P. Y.	Evaluation of Experimental Nylon Yarn and Fabric

CHAPTER IX

SECTION 2

MILITARY SPECIFICATIONS

Number	Title
MIL-R-6336E(ASG)	Release, Automatic, Ripcord - Type F-1A
MIL-R-6887A(USAF)	Release, Personnel Parachute Harness, Type B-2A
MIL-R-6961(USAF)	Release Kit Assembly, Aerial Delivery Container, Type A-1
MIL-C-6596B(USAF)	Container; Aerial Delivery, AN/URC-4, Radio and Accessories, Metal, Type A-20
MIL-P-6634B(ASG)	Parachute, Cargo, 500 lb. Capacity, Type G-13
MIL-P-6635A(ASG)	Parachute - FIST Ribbon, General Specification for Construction of
MIL-P-6645C(USAF)	Parachutes; General Specifications for Man-Carrying
MIL-C-7554(USAF)	Container Kits, Aerial Delivery
MIL-D-7567(USAF)	Decal, Parachute, Webbing
MIL-P-7620(USAF)	Parachutes, Cargo, General Specification for
MIL-D-7626(USAF)	Drop Kit Components, Heavy Packaging, Packing and Marking for Shipment of
MIL-C-8121(USAF)	Canopy, Tower Parachute, Free Fall Type J-1
MIL-C-8137(USAF)	Canopy, Tower Parachute, Controlled Fall Type J-2
MIL-P-8322(USAF)	Parachutes, Personnel, Assembly and Rigging Instructions
MIL-P-9035(USAF)	Parachute, Cargo Extraction 24 Ft. Diameter, FIST Ribbon, Type MC-1
MIL-C-9401(USAF)	Canopy, Parachute, Ring Slot, General Specification for
MIL-E-9056(USAF)	Deceleration Parachute Systems, Aircraft, General Requirements for
MIL-P-25063(USAF)	Parachute Recovery Systems, Missile and Drone, General Requirements for Development of
MIL-P-8805A	Parachute, Ribbed Guide Surface; General Specification for Construction of
MIL-F-6031	Parachute, Experimental; Inspection and Testing of
MIL-H-7195	Hardware, Parachute, General Requirement for
MIL-H-7750	Housing, Parachute, Ripcord
MIL-A-8118A	Aerial Delivery Kits and Components, Heavy Cargo and Vehicles
MIL-W-4088B(USAF)	Webbing, Textile, Woven, Nylon
MIL-W-5787B	Webbing, Textile, Nylon, Heavy Duty
MIL-W-005665C	Webbing, Textile, Woven, Cotton Warp
MIL-W-5625	Webbing, Nylon, Tubular
MIL-W-6134	Webbing, Nylon-Spun Nylon Filler
MIL-W-5666	Webbing, Nylon, Multiple-Tubular
MIL-R-5608D	Ribbon, Nylon, Parachute
MIL-C-7020B(ASG)	Cloth, Nylon, Parachute
MIL-C-7350B(ASG)	Cloth, Nylon, Parachute, Cargo
MIL-C-8021A	Cloth, Nylon, Drag Parachute
MIL-C-8008(USAF)	Cloth, Rayon, Parachute
MIL-T-5038	Tape, Nylon, Reinforcing
MIL-T-5663A	Tape, Textile
MIL-T-6363(USAF)	Tape, Textile, Woven, Nylon
MIL-T-5661A	Tape, Cotton, Reinforcing
MIL-T-7807	Thread, Nylon
MIL-T-5660A(ASG)	Thread, Cotton, High Tenacity
MIL-C-4233(USAF)	Cord, Rayon, Without Core, Braided
MIL-C-5040A(ASG)	Cord, Nylon
MIL-C-7515(USAF)	Cord, Nylon, Coreless
MIL-C-7219A(ASG)	Cloth, Nylon Plied Yarns, for Parachute Packs

Number	Title
CCC-D-771B	Duck, Cotton, Plied Yarns
MIL-I-6063(USAF)	Ink, Marking
MIL-F-6903	Fluid, Parachute Marking
MIL-C-10362(ORD)	Cutter, Reefing Line, M2
DDD-S-751	Stitches, Seams, and Stitching